A. S. Anderson

B. S. Feb 1854

S. S. Anderson

Bo. S. Feb / 1854

THE

RUDIMENTS

OF THE

ART OF BUILDING;

REPRESENTED IN FIVE SECTIONS:

I. The General Principles of Construction;
II. Materials used in Building;
III. Strength of Materials;
IV. Use of Materials;
V. Working Drawings, Specifications, and Drawings.

FOR THE USE OF

Architects, Builders, Draughtsmen, Machinists, Engineers and Mechanics.

EDITED BY JOHN BULLOCK,
ARCHITECT, CIVIL ENGINEER, MECHANICIAN, AND EDITOR OF "THE AMERICAN ARTISAN."

NEW YORK:
STRINGER & TOWNSEND, PUBLISHERS,
222 BROADWAY.
1853.

STEREOTYPED BY GRIFFIN & FARNSWORTH,
49 JOHN STREET, NEW YORK

CONTENTS.

PREFACE.

It required but a little alteration to suit Mr. Dobson's excellent treatise to American readers. As an elementary treatise it has no equal.

In the various departments, we have made free use of *Weale's Series*, copying from it such information as seemed appropriate and valuable, sometimes using the very words, and at others simply condensing its information.

It was not without much hesitation that we retained the algebraic signs made use of in the book, especially in section I; but such readers as do not understand them, may safely omit them without losing the substance of the work, while those to whom they are familiar will find them valuable.

It is to be regretted that authors make such frequent use of signs and terms in rudimentary works as are not familiar to the general reader; and it is also to be regretted that the readers, and especially students, do not acquire a knowledge of those signs and terms.

This work is intended as a "first book on the art of building, designed for the use of young persons who are about to commence their professional training for any pursuit connected with the erection of buildings; and, also, for the use of amateurs, who wish to obtain a general knowledge of the subject, without devoting to it the time requisite for the study of the larger works that have been written on the different branches of construction."

The list of North American woods which appears in the appendix, is substantially the same as that made by the jury at the London World's Fair. The other tables are compiled from various sources.

JOHN BULLOCK, EDITOR.

APPENDIX.

WOODS OF NORTH AMERICA.

1. *Abies alba*, or white spruce; weighs 23 lbs. 13 oz. per cubic foot; specific gravity, .381.

2. *Abies canadensis*, or hemlock-spruce; common in Upper Canada; weighs 23 lbs. 0 oz. per cubic foot, and has a specific gravity of .368.

3. *Acer eriocarpum*, or soft maple; common in Upper Canada; weighs 36 lbs. 14 oz., and has a specific gravity of .590.

All the above are used in carpentry.

4. *Acer negrundo*, or box-elder, ash-leaved maple; common in the United States; weighs 24 lbs. per cubic foot, and has a specific gravity of .384.

5. *Acer rubrum*, or red maple; common in the United States; weighs 38 lbs. 5 oz. per cubic foot—has a specific gravity of .613.

6. *Ascer saccharinum*, or sugar mable; common in the United States; weighs 38 lbs. 6 oz. per cubic foot, and has a specific gravity of .614.

7. *Ascer saccharinum*, or bird's-eye maple; common in Upper Canada; used in ornamental work by carpenters and joiners; weighs 40 lbs. 15 oz. per cubic foot, and has a specific gravity of .655.

8. Curly maple; common in Upper Canada; used in common carpentry work; has a specific gravity of .586, and weighs 36 lbs. 10 oz. per cubic foot.

9. Hard maple; also common in Upper Canada; weighs 39 lbs. per cubic foot, and has a specific gravity of .634.

10. *Betula nigra*, or black birch; common in Upper Canada; is much used for ship-building in Canada and Nova Scotia, but is not a durable wood; it weighs 35 lbs. 7 oz. per cubic foot, and has a specific gravity of .567.

11. Birch; an inferior wood—common in Canada and the Northern States; weighs 30 lbs. 11 oz. per cubic foot, and has a specific gravity of .491.

12. Butter wood; used in ship-building; has a specific gravity of .460, and weighs 28 lbs. 12 oz. per cubic foot.

13. *Carya porcina*, or pignut hickory; common in the United States; is the strongest and best kind of hickory; it weighs 49 lbs. 8 oz. per cubic foot, and has a specific gravity of .690.

14. *Carya sulcata*, or shell-bark hickory; common in the United States; weighs 43 lbs. 2 oz. per cubic foot, and has a specific gravity of .690.

15. Hickory; common in the United States; weighs 47 lbs. 8 oz. per cubic foot, and has a specific gravity of .760.

16. *Castanea vesca*, or chesnut; common in the United States; has a specific gravity of .404, and weighs 25 lbs. 4 oz. per cubic foot.

17. *Celtis crassifolia*, or hack berry; is a tough and elastic wood, weighing 38 lbs. 6 oz. per cubic foot, and has a specific gravity of .614.

18. *Cerasus virginiana*, or wild cherry; common in the United States; the bark is used medicinally; has a specific gravity of .515, and weighs 32 lbs. 3 oz. per cubic foot.

19. *Cerasus canadensis*, or red bud, Judas tree; a close-grained and compact wood, having a specific gravity of .535, and weighs 33 lbs. 7 oz. per cubic foot.

20. *Cornus florida*, or dog-wood; a hard, close-grained, and strong wood, weighing 47 lbs. 4 oz. per cubic foot, and having a specific gravity of .756.

21. *Cupressus disticha*, or cypress; common in the United States; grows to an immense size; is much used for shingles; weighs 22 lbs. 13 oz. per cubic foot, and has a specific gravity of .365.

22. *Diosyrus virginiana*, or persimon; a hard, close-grained wood; weighs 44 lbs. 6 oz. per cubic foot, and has a specific gravity of .710.

23. *Fagus americana*, or white beach; common in the United

States; is used in dry carpentry; weighs 42 lbs. 11 oz. per cubic foot, and has a specific gravity of .674.

24. *Fagus ferrugina*, or beech; common in Upper Canada, used in dry carpentry; the wood has a more rufous tint of color than common beech; it weighs 36 lbs. 9 oz. per cubic foot, and has a specific gravity of .585.

25. *Fraxinus americanus*, or American ash; weighs 35 lbs. 10 oz. per cubic foot, and has a specific gravity of .570;—is tough, and elastic.

26. White ash; weighs 30 lbs. 14 oz. per cubic foot, and has a specific gravity of .494.

27. *Gleditschia triacauthus*, or honey locust; is a very hard wood and splits easily, having a specific gravity of .646, and weighing 40 lbs. 6 oz. per cubic foot.

28. *Gymnocladus canadensis*, or coffee tree; is a hard, compact, strong, and tough wood, having a specific gravity of .647, and weighing 40 lbs. 7 oz. per cubic foot.

29. *Juglans alba*, or hickory; has a specific gravity of .770, and weighs 48 lbs. 2 oz. per cubic foot.

30. *Juglans cinerea*, or butternut; has a specfiic gravity of from .376 to .487, and weighs from 22 to 30 lbs. per cubic foot.

31. White walnut.

32. *Juglans nigra*, or black walnut; weighs 28 lbs. 15 oz. per cubic foot, and has a specific gravity, of .483 It is a strong and tough wood, not liable to split, and is much used in carpentry work.

33. *Juniperus bermudiana*, or red or pencil cedar; is used in ship-building and for making pencils.

34. The Virginia cedar is used for the same purpose, but is not considered as good as that from Bermuda.

35. *Larix americana*, or hackmatack; much used and esteemed in British North America for ship-building; has a specific gravity of about .600, and weighs about 36 lbs. per cubic foot.

36. The tamarack is a wood much used for ship-building in

British North America; it has a specific gravity of .383, and weigh 23 lbs. 15 oz. per cubic foot.

37. *Cedar.*—The samples at the World's Fair had a specific gravity of from .294 to .314, and weighed from 18 lbs. 6 oz. to 19 lbs. 10 oz. per cubic foot.

38. *Liriodenron tulipifera*, or yellow poplar; is common in the United States; has a specific gravity .287, and weighs 24 lbs. 8 oz. per cubic foot.

39. *Morus rubra*, or red mulberry; weighs 35 lbs. 1 oz. per cubic foot, and has a specific gravity of .56I.

40. *Nyssa Multiflora*, or black gum, or sour gum; weighs 40 lbs. 6 oz. per cubic foot, and has a specific gravity of .646.

41. *Ostrya virginica*, or iron wood; weighs 48 lbs. 11 oz. per cubic foot, and has a specific gravity of .779.

42. *Picea balsamea*, or balsam; is used in carpentry; has a specific gravity of .304, and weighs 19 lbs. per cubic foot.

43. *Pinus nutis*, or white pine; has a specific gravity of .376, and weighs 23 lbs. 8 oz. per cubic foot.

44. *Pinus resinosa*, or American red pine; is used in carpentry; weighs 26 lbs. 11 oz. per cubic foot, and has a specific gravity of .427.

45. Red Pine; is a strong wood used in carpentry; has a specific gravity of .455, and weighs 28 lbs. 7 oz. per cubic foot.

46. *Pinus rigida*, or pitch pine; is a strong wood, weighing 32 lbs. per cubic foot, and having a specific gravity of .512.

47. *Platanus occidentalis*, or bullon-wood, or sycamore; is much used for making beadsteads; has a specific gravity of .424, and weighs 26 lbs. 8 oz. per cubic foot.

48. *Populus*, or poplar; is a light, inferior wood.

49. Cherry wood; weighs 29 lbs. 15 oz. per cubic foot, and has a specific gravity of .479.

50. Quebec oak; is much used for ship building, but is not durable.

51. *Quercus alba*, or white oak; weighs 40 lbs. per cubic foot, and has a specific gravity of .64.

52 *Quercus rubra*, or red oak; weighs 32 lbs. 2 oz. per cubic foot, and has a specific gravity of .514.

53. *Quercus tinctoria*, or black oak; weighs 34 lbs. 13 oz., and has a specific gravity of .558.

54. *Quercus virens*, or live oak; is the heaviest and hardest of the oaks; has a specific gravity of .100, and weighs 56 lbs. 4 oz. per cubic foot.

55. *Robenia pseud acacia*, or locust, or treenail; so called because used principally for treenails.

56. *Sassafras officinale*, or sassafras tree.

57. *Tilia americana*, or bass-wood; is even in grain, weighs 25 lbs. per cubic foot, and has a specific gravity of .400.

58. *Ulmus americana*, or elm; weighs 36 lbs. 11 oz. per cubic foot, and has a specific gravity of .587.

59. Red elm—used by wheelwrights.

60. White elm.

61. Rock elm.

62. Swamp elm. These elms are all quite similar.

63. Quebec rock elm, or wych hazel; used in ship-building in Canada; has a specific gravity of .546, and weighs 34 lbs. 2 oz. per cubic foot.

64. *Uvaria triloba*, or paw paw; weighs 51 lbs. 6 oz. per cubic foot, and has a specific gravity of .359.

STONE.

13 cubic feet of marble weigh 1 ton.
13½ feet of granite weigh 1 ton.
The following table is from Dobson :—

WEIGHT OF TIMBER.

34	cubic feet	of	Mahogany	weigh	one ton.
39	"	"	Oak,	"	"
45	"	"	Ash,	"	"
51	"	"	Beech,	"	"
60	"	"	Elm,	"	"
65	"	"	Fir.	"	"

WAGES.

The price of labor in different portions of the United States, varies more than three hundred per cent.

RUDIMENTS

OF THE

ART OF BUILDING.

SECTION I.

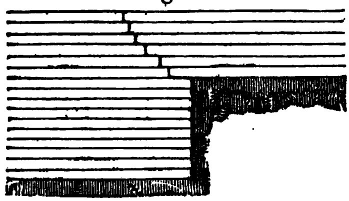
GENERAL PRINCIPLES OF CONSTRUCTION.

FOUNDATIONS.

1. IN preparing the foundation for any building, there are two sources of failure which must be carefully guarded against: viz., inequality of settlement, and lateral escape of the supporting material; and, if these radical defects can be guarded against, there is scarcely any situation in which a good foundation may not be obtained.

2. *Natural Foundations.*—The best foundation is a *natural* one, such as a stratum of rock, or compact gravel. If circumstances prevent the work being commenced from the same level throughout, the ground must be carefully *benched out*, *i. e.*, cut into horizontal steps, so that the courses may all be perfectly level. It must also be borne in mind that all work will settle, more or less, according to the perfection of the joints, and therefore in these cases it is best to bring up the foundations to a uniform level, with large blocks of stone, or with concrete, before commencing the superstructure, which would otherwise settle most over the deepest parts, on account of the greater number of mortar joints, and thus cause unsightly fractures, as shown in fig. 1.

Fig. 1.



3. Many soils form excellent foundations when kept from the weather, which are worthless when this cannot be effected. Thus blue shale, which is often so hard when the ground is first opened as to require blasting with gunpowder, will, after a few days' exposure, slake and run into sludge. In dealing with soils of this kind nothing is required but to keep them from the action of the atmosphere. This is best done by covering them with a layer of concrete, which is an artificial rock, made of sand and gravel, cemented with a small quantity of lime. For want of this precaution many buildings have been fractured from top to bottom by the expansion and contraction of their clay foundations during the alternations of drought and moisture, to which they have been exposed in successive seasons.

4. *Artificial Foundations.*—Where the ground in its natural state is too soft to bear the weight of the proposed structure, recourse must be had to artificial means of support, and, in doing this, whatever mode of construction be adopted, the principle must always be that of extending the bearing surface as much as possible; just in the same way, that, by placing a plank over a dangerous piece of ice, a couple of men can pass over a spot which would not bear the weight of a child. There are many ways of doing this—as by a thick layer of concrete, or by layers of planking, or by a net-work of timber, or these different methods may be combined. The weight may also be distributed over the entire area of the foundation by inverted arches.

5. The use of timber is objectionable where it cannot be

kept constantly wet, as alternations of dryness and moisture soon cause it to rot, and for this reason concrete is very extensively used in situations where timber would be liable to decay.

6. In the case of a foundation partly natural and partly artificial, the utmost care and circumspection are required to avoid unsightly fractures in the superstructure ; and it cannot be too strongly impressed on the mind of the reader, that it is not an *unyielding*, but a *uniformly yielding* foundation that is required, and that it is not the *amount*, so much as the *inequality*, of settlement that does the mischief.

The second great principle which we laid down at the commencement of this section was—To prevent the lateral escape of the supporting material. This is especially necessary when building in running sand, or soft, buttery clay, which would ooze out from below the work, and allow the superstructure to sink. In soils of this kind, in addition to protecting the surface with planking, concrete, or timber, the whole area of the foundation must be inclosed with piles driven close together ;—this is called *sheet-piling*.

7. Where there is a hard stratum below the soft ground, but at too great a depth to allow of the solid work being brought up from it without greater expense than the circumstances of the case will allow, it is usual to drive down wooden piles, shod with iron, until their bottoms are firmly fixed in the hard ground. The upper ends of the piles are then cut off level, and covered with a platform of timber on which the work is built in the usual way.

8. Where a firm foundation is required to be formed in a situation where no firm bottom can be found within an available depth, piles are driven, to consolidate the mass, a few feet apart over the whole area of the foundation, which is surrounded by a row of sheet-piling to prevent the escape of the soil ; the space between the pile heads is then filled to the depth of several feet with stones or concrete, and the

whole is covered with a timber platform, on which to commence the solid work.

9. *Foundations in Water.*—Hitherto we have been describing ordinary foundations; we now come to those cases in which water interferes with the operations of the builder, oftentimes causing no little trouble, anxiety, and expense.

Foundations in water may be divided under three heads:

1st. Foundations formed wholly with piles:

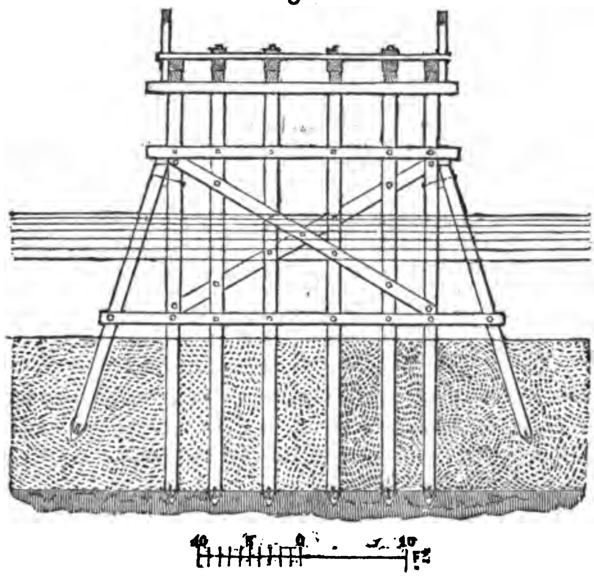
2d. Solid foundations laid *on* the surface of the ground, either in its natural state, or roughly leveled by dredging:

3d. Solid foundations laid *below* the surface, the ground being laid dry by cofferdams.

10. *Foundations formed wholly of Piles.*—The simplest foundations of this kind are those formed by rows of wooden piles braced together so as to form a skeleton pier for the support of horizontal beams; and this plan is often adopted in building jetties, piers of wooden bridges, and similar erections where the expense precludes the adoption of a more permanent mode of construction; an example of this kind is shown in fig. 2.

In deep water, the bracing of the piles becomes a difficult matter, and an ingenious expedient for effecting this was made use of by Mr. Walker, in the erection of the Ouse Bridge, on the Leeds and Selby Railway, A.D. 1840. This consisted in rounding the piles to which the braces are attached for a portion of their length, to allow the cast-iron sockets in which they rest to descend and take a solid bearing upon the square shoulders of the brace-piles. After the brace-piles were driven, the braces were bolted into their sockets and dropped down to their required position, and their upper ends were then brought to their places and bolted to the superstructure.

Fig. 2.



11. There is always, however, a great objection to the use of piles partly above and partly under water, namely, that, from the alternations of dryness and moisture, they soon decay at the water-line, and erections of timber require extensive repairs from this cause. In tidal waters, too, they are often rapidly destroyed by the worm, unless great expense is undergone in sheathing them with copper.

To obviate the inconveniences attending the use of timber, cast-iron is sometimes used as a material for piles ; but this again is objectionable in salt water, as the action of the sea-water upon the iron converts it into a soft substance which can be cut with a knife, resembling the Cumberland lead used for pencils.

12. In England, in situations where a firm hold cannot be obtained for a pile of the ordinary shape, such as shifting sand, Mitchell's patent screw-piles are used with great advantage. These piles terminate at the bottom in a large

iron screw 4 ft. in diameter, which, being screwed into the ground, gives a firm foot-hold to the pile. This is a very simple and efficient mode of obtaining a foundation where all other means would fail, and has been used in erecting light-houses on sand-banks with great success. The Maplin sand light-house at the mouth of the Thames, and the Fleetwood light-house, at Fleetwood, in Lancashire, both erected A. D. 1840, may be instanced.

13. An ingenious system of cast-iron piling was adopted by Mr. Tierney Clark in the erection of the Town Pier at Gravesend, Kent, A. D. 1834, in forming a foundation for the cast-iron columns, supporting the superstructure of the T head of the pier. Under the site of each column were driven three cast-iron piles, on which an adjusting plate was firmly keyed, forming a broad base for the support of the column, which was adjusted to its correct position, and bolted down to the adjusting plate.

14. A kind of foundation on the same principle as piling has been lately much used in situations where ordinary piling cannot be resorted to with advantage. The method referred to consists in sinking hollow cast-iron cylinders until a hard bottom is reached. The interior of the cylinder is then pumped dry, and filled up with concrete, or some equally solid material, thus making it a solid pier on which to erect the superstructure. The cylinders are made in lengths, which are successively bolted together as each previous length is lowered, the excavation going on at the bottom, which is kept dry by pumping. It often happens, however, in sinking through sand, that the pressure of the water is so great as to blow up the sand at the bottom of the cylinder; and when this is the case, the operation is carried on by means of a large auger, called a miser, which excavates and brings up the materials without the necessity of pumping out the water. The lower edge of the bottom length of each cylinder is made with a sharp edge, to enable it to penetrate the soil with greater ease, and to enter the hard

bottom stratum on which the work is to rest. This method was adopted by Mr. Redman in the erection of the Terrace Pier at Gravesend, Kent, finished A. D. 1845.

15. Before closing our remarks on pile foundations, we must mention a very curious system of carrying up a foundation through loose, wet sand, which is practised in India and China, and is strictly analogous to the sinking of cast-iron cylinders just described.

It consists in sinking a series of wells close together, which are afterwards arched over separately, and covered with a system of vaulting on which the superstructure is raised. The method of sinking these wells is to dig down, as far as practicable, without a lining of masonry, or until water is reached; a wooden curb is then placed at the bottom of the excavation, and a brick cylinder raised upon it to the height of 3 or 4 ft. above the ground. As soon as the work is sufficiently set, the curb and the superincumbent brick-work are lowered by excavating the ground under the sides of the curb, the peculiarity of the process being that the well-sinker works under water, frequently remaining submerged more than a minute at a time. These cylinders have been occasionally sunk to a depth of 40 ft.

16. *Solid Foundations simply laid on the Surface of the Ground.*—Where the site of the intended structure is perfectly firm, and there is no danger of the work being undermined by any scour, it will be sufficient to place the materials on the natural bottom, the inequalities of surface being first removed by dredging or blasting.

17. *Pierre perdue.*—The simplest mode of proceeding is to throw down masses of stone at random over the site of the work until the mass reaches the surface of the water, above which the work can be carried on in the usual manner. This is called a foundation of "*pierre perdue*," or random work, and is used for breakwaters, foundations of sea-walls, and similar works.

18. *Coursed Masonry.*—Another way, much used in harbor work, is to build up the work from the bottom (which must be first roughly leveled) with large stones, carefully lowered into their places ; and this is a very successful method where the stones are of sufficient size and weight to enable the work to withstand the run of the sea. The diving-bell affords a ready means of verifying the position of each stone as it is lowered.

19. *Béton.*—On the continent, foundations under water are frequently executed with blocks of béton or hydraulic concrete, which has the property of setting under water. The site of the work is first inclosed with a row of sheet piling, which protects the béton from disturbance until it has set. This system is of very ancient date, being described by Vitruvius, and was practised by the Romans, who have left us many examples of it on the coast of Italy. The French engineers have used béton in the works at Algiers, in large blocks of 324 cubic feet, which were floated out and allowed to drop into their places from slings. This method, which proved perfectly successful, was adopted in consequence of the smaller blocks first used being displaced and destroyed by the force of the sea.

20. *Caissons.*—A caisson is a chest of timber, which is floated over the site of the work, and, being kept in its place by guide piles, is loaded with stone until it rests firmly on the ground. The masonry is then built on the bottom of the caisson, and when the work reaches the level of the water the sides of the caisson are removed.

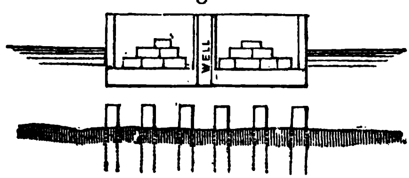
This method of building has been much used on the continent of Europe.

21. An improvement on the above method consists in dredging out the ground to a considerable depth, and putting in a thick layer of béton on which to rest the bottom of the caisson.

22. There is a third method of applying caissons which is

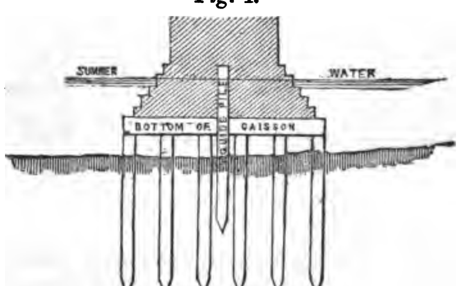
practised on the continent of Europe, and which is free from the objections which commonly attend the use of caissons. A firm foundation is first formed by driving piles a few feet apart over the whole site of the foundation. The tops of the piles are then sawn off under water just enough above the ground to allow of their being all cut to the same level. The caisson is then floated over the piles, and, when in its proper position, is sunk upon them, being kept in its place by a few piles left standing above the others, the water being kept out of the caisson by a kind of well, constructed round each of these internal guide piles, which are built up into the masonry. This method of building in caissons on pile foundations is shown in figs. 3 and 4. The piers of the

Fig. 3.



Pont du Val Benoît at Liége, built A. D. 1842, which carries the railway across the Meuse, have been built on pile foundations, in the manner here described.

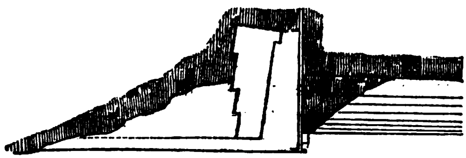
Fig. 4.



23. *Solid Foundations laid in Cofferdams.*—There are many circumstances under which it becomes necessary to

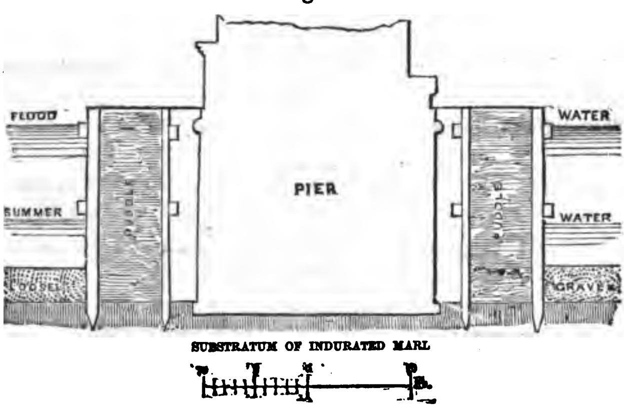
lay the bottom dry before commencing operations. This is done by inclosing the site of the foundation with a water-tight wall of timber, from within which the water can be pumped out by steam power or otherwise. Sometimes, in shallow water, it is sufficient to drive a single row of piles only, the outside being protected with clay, as shown in fig. 5; but in deep water two or even four rows of piles will be

Fig, 5.



required, the space between them being filled in with well-rammed *puddle*, so as to form a solid water-tight mass. (See fig 6.) The great difficulties in the construction of a

Fig. 6.



cofferdam are—1st, to keep it water-tight; and, 2nd, to support the sides against the pressure of the water outside, which in tidal waters is sometimes so great as to render it necessary to allow a dam to fill to prevent its being crushed.

24. In order to save timber, and to avoid the difficulty of keeping out the bottom springs, it has been proposed by a French engineer, after driving the outer row, to dredge out the area thus inclosed, and fill it up to a certain height with béton. The cofferdam is then to be completed by driving an inner row of piles resting on the béton, and puddling between the two rows in the usual manner; and the masonry is carried up on the béton foundation thus prepared. This construction is shown in fig. 7.

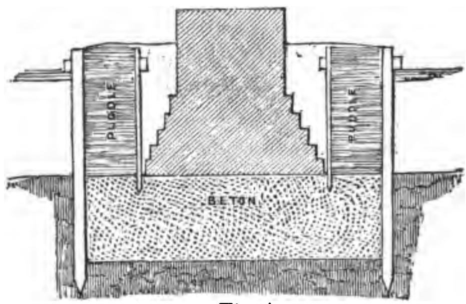


Fig. 7.

25. Concrete is a valuable material when applied in a proper manner, viz., in underground works where it is confined on all sides, and is, consequently, subjected to little cross strain; but it is not fit to be used *above* ground as a substitute for masonry, and will not bear exposure to water.

26. Concrete is made of gravel, sand, and ground lime, mixed together with water; the slaking of the lime taking place whilst in contact with the sand and gravel. It is difficult to give any definite proportions for the several ingredients, but the principle to be followed in proportioning the several quantities of sand and stones should be to form as much as possible a solid mass, for which purpose it is desirable that the stones should be of various sizes, and angular rather than rounded. The common material is unscreened gravel, containing a considerable portion of sand and large and small pebbles, but small irregular fragments of broken

stone, granite chippings, and the like, are of great service, as they interlace each other and bind the mass together. The proportion of lime to sand should be such as is best suited to form a cement to connect the stones. This must depend in a great measure on the quality of the lime used; the pure limes requiring a great proportion of sand, whilst the stone limes, and those containing alumina, silica, and metallic oxides, require a much smaller proportion.

27. The lime and gravel should be thoroughly incorporated by being repeatedly turned over with shovels, sufficient water being added to ensure the thorough slaking of the lime without drowning it. Concrete should not be thrown into water, because ordinary stone lime will not set under such circumstances; and it should be carefully protected from any wash or run of water, which would have the effect of washing out the lime, and leaving the concrete in the state of loose gravel. Concrete made in the way just described swells slightly before setting, from the expansion due to the slaking of the lime, and does not return to its original bulk. This property makes it valuable for underpinning foundations and similar purposes.

28. *Béton.*—Béton may be considered as hydraulic concrete; that is, concrete made with hydraulic lime; and is chiefly used in submarine works, as a substitute for masonry, in situations where the bottom cannot be laid dry. It differs from ordinary concrete inasmuch as the lime must be slaked before mixing with the other ingredients, and it is usual to make the lime and sand into mortar before adding the stones. Concrete also is used hot, whilst béton is allowed to stand before being used, in order to ensure the perfect slaking of every particle of lime. Belidor directs that the mortar shall first be made, with pozzuolana, sand, and quicklime. When the mortar is thoroughly mixed, the stones are to be thrown in (not larger than a hen's egg), and also iron dross well pounded; the whole is then to be thoroughly incorpor-

ated, and left for twenty-four hours. The proportions are to be as follows :—

Pozzuolana	. 12	parts.
Sand	6	"
Good quicklime	9	"
Small stones .	13	"
Ground slag .	3	"
	43	

The béton is to be lowered into the water in a box, with a bottom so constructed that it can be opened, and its contents discharged, by pulling a cord, so as to deposit the béton on the bottom without having to fall through a depth of water, which might wash away the lime. For the same reason it is necessary, before commencing, to lay the béton, to surround the site with sheet-piling, to protect it from the action of the water, and to guard against the danger of the softer portions of the work being carried away by tempests before they become consolidated.

29. The ordinary method of using béton on the Continent is in alternate layers of béton and rubble stone. A layer of béton, about a foot in thickness, is first spread over the whole area of the foundation, and on this is laid a stratum of rubble, which, sinking into the soft béton, becomes thoroughly incorporated with it. On this is laid another layer of béton, followed by another course of rubble; this system being pursued until the work reaches the intended height.

30. *Pile-driving.*—The usual method of pile-driving is by a succession of blows given by a heavy block of wood or iron (called a monkey, or ram, or tup), which is raised by a rope or chain passed over a pulley fixed at the top of an upright frame of timber, and allowed to fall freely on the head of the pile to be driven. There are a large number of pile-drivers of different styles in use. The one most commonly used in the United States is Captain Cram's.

31. In selecting timber for piles, care should be taken to choose that which is straight-grained and free from knots and ring shakes. Larch, fir, beech, and oak, are the woods most esteemed. In situations exposed to the worm, there is little difference in the durability of the best and the worst timber, if unprepared, and, therefore, it is always safest to use some preserving process.

32. Piles which have to be driven through hard ground require to be *rung*, that is, to have an iron hoop fixed tightly on their heads, to prevent them from splitting, and also to be *shod* with iron shoes ; the shoes may be of wrought or of cast iron. For single piles the point of the shoe is placed in the centre of the pile ; but for sheet-piling, the shoes are made not with a point, but with an edge, which is not level, but slightly inclined, so as in driving to give the pile a *drift* towards the pile last driven, by which means a close contact is ensured. Great care is required, in shoeing a pile, to ensure that the shoe is driven perfectly home. The advantage of a cast-iron shoe is, that the inside can be formed with a square abutment on which the pile rests, whilst a wrought-iron shoe has to be driven up until the toe of the pile is *wedged* tight, and, as the force with which the pile is driven into the ground greatly exceeds that with which the shoe is driven on the pile, it will often happen that the shoe will burst open, and allow the point of the pile to be crushed before it is down to its full depth.

33. Sheeting piles should be carefully fitted to each other before driving, otherwise they cannot be expected to come in close contact when driven In some few cases it is worth while to groove and tongue the edges, but this is seldom done, and if the piles are perfectly parallel and truly driven, the swelling of the wood when exposed to moisture will generally secure a tight joint.

34. As a general rule, broken timber, that is, timber cut out of larger balks, should be avoided. A 10-in. stick of Swedish timber will drive better and with less risk of split-

ing than a quarter of a 20-in. balk of best Dantzic. If piles must be cut from large balks, the heart of the wood should, if possible, be left in the centre of the pile.

35. In driving sheet-piling, the piles are kept in their proper position by horizontal pieces of timber called *wales*, which are fixed to guide piles previously driven. In driving coffer-dams and similar works, the wales are seldom placed below the water-line, but this may be done with great benefit by attaching the wales to hoops dropped over the heads of the guide piles, and pushed down as low as the ground will permit. In driving into or through a hard stratum, it is desirable that the auger should precede the driving, as it will save much time, and much injury to the piles; and in all cases where a hard-bearing stratum has to be reached at a variable depth, the boring-rod should be used to ascertain the length of pile required, as nothing is more vexatious than finding a pile a few inches too short when driven, or, on the other hand, having to cut off 5 or 6 ft. of good timber, which must be needlessly wasted.

36. Many writers have endeavored to lay down rules for calculating the effect of a given blow in sinking a pile, but investigations of this kind are of little practical value, because we can never be in possession of sufficient data to enable us to obtain even an approximate result. The effect of each blow on the pile will depend on the force of the blow, the velocity of the ram, the relative weights of the ram and the pile, the elasticity of the pile head, and the resistance offered by the ground through which the pile is passing, and as we never can ascertain the two last-named conditions with any certainty, any calculations in which they are only assumed must of necessity be mere conjectures.

37. Piles driven for temporary purposes are, at the completion of their term of service, either drawn for the value of the timber and iron shoes, or cut off at the level of the ground if they are in situations where the drawing of the piles might cause any risk to the adjacent work. When

sheet-piling has been driven round the foundations of any work, as in forming a cofferdam round the pier of a bridge, there will always be, in the event of its being drawn, the risk of the ground settling down to fill up the vacancy thereby occasioned ; but in clay or marl soils this is not the greatest danger, for the water scours out and enlarges the race thus formed, and the bottom speedily becomes broken up, nearly to the depth to which the piles were driven. As a general rule, therefore, it may be laid down, that piles in such situations should never be drawn, but should be cut off at the level of the ground, nnd this may be done in various ways. 1st. By common means, the men working in a diving bell, or with diving-helmets. 2d. By machinery especially constructed for the purpose. 3d. In the case of cofferdams, by cutting the piles nearly through from the inside with the adze, leaving the water on the outside of the piles to complete the operation on the removal of the strutting.

38. There are many cases, however, in which it becomes necessary to draw piles, and the modes in which this may be done are almost infinite. The common plan, where the situation will admit of it, is to make use of a balk of timber as a lever, one end of which is shackled to the head of the pile, whilst to the other end is applied such power as can most readily be obtained.

39. A very simple method of drawing piles is by means of a powerful screw, of which one end is hooked to a shackle passing round the head of the pile, whilst the other passes through a cross-head, resting firmly on temporary supports placed on each side of the pile.

40. *Cofferdams.*—A cofferdam may be described as a water-tight wall, constructed round the site of any work, for the purpose of laying dry the bottom by pumping out the water from the area thus enclosed. In some situations, this may be effected by earthern dams, by bags of clay piles on each other, or by rough caissons, without top or bottom,

filled with clay, and sunk in line round the space to be enclosed; but in the majority of cases, the method is to drive two or more rows of close piling, and to fill up the space between them with clay puddle.

41. Cofferdams are sometimes formed, in shallow water, with a single row of sheet-piling; but this is very precarious work, as, unless the piles are fitted together with great truth, it is impossible to keep the joints close, and to prevent leakage. A single row of sheet-piling may, however, be often used with great advantage as a protection and support in front of an earthen dam, and this is a very economical and satisfactory method of proceeding where there is no depth of water.

42. Cofferdams are subject to heavy external pressure from the water round them, which would crush them in, were they not very firmly strutted. In cofferdams inclosing a small area, as, for instance, the site of the pier of a bridge, the strutting is placed from side to side, in the manner that will give the greatest facility for carrying on the work, the struts being gradually removed as the latter proceeds.

In constructing dams in front of a wharf wall, or similar work, the strutting requires to be effected in a different manner, and the plan usually adopted is to form a series of buttresses, or counterforts, at short intervals, from which the intermediate portions of the dam can be strutted with raking, horizontal struts. The strength given to these counterforts must, of course, depend on the amount of pressure to come on the dam.

43. In rivers subject to heavy freshets it is common, in constructing cofferdams, to keep the top of the dams below the flood level, as it is generally less expensive to pump out the water from the interior of the dam occasionally, than to construct and maintain a dam which should sustain the pressure of the flood waters; and it is always advisable to provide every dam with a sluice, by mean of which the water

can be admitted, if there is any fear of injury from a sudden freshet or from any other cause. In tidal waters the operation of closing a dam is sometimes rather hazardous (unless it can be performed at low water), from the tide falling outside, without the dead water inside being able to escape sufficiently quick through the sluices to maintain an equilibrium ; and, unless the piles and puddle wall are sufficiently strong to resist this outward pressure, the work will be violently strained, and often permanently injured. When the site to be inclosed is above the level of low water, *half-tide dams* are sometimes resorted to. A half-tide dam is one which is covered and filled at every tide, and emptied by sluices at low water, the available working hours lasting from the time the bottom runs dry until the flood tide reaches the top of the dam.

44. The principal difficulties in the construction of coffer-dams may be thus briefly stated :—

1st. To obtain a firm foothold for the piles, which, in either rock or mud, is a matter of great difficulty.

2d. To prevent leakage between the surface of the ground and the bottom of the puddle.

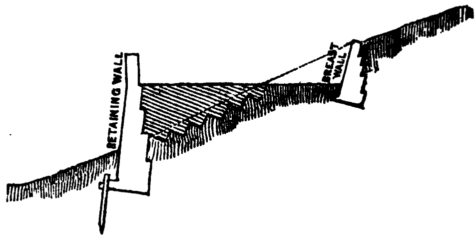
3d. To prevent leakage through the puddle wall.

4th. To keep out the bottom springs.

RETAINING WALLS.

45. The name of *retaining wall* is applied generally to all walls built to support a mass of earth in an upright or nearly upright position ; but the term is, strictly speaking, restricted to walls built to retain an artificial bank, those erected to sustain the face of the solid ground being called *breast walls*. (See fig. 8.

Fig. 8.



46. *Retaining Walls.*—Many rules have been given by different writers for calculating the thrust which a bank of earth exerts against a retaining wall, and for determining the form of wall which affords the greatest resistance with the least amount of material. The application of these rules to practice is, however, extremely difficult, because we have no means of ascertaining the exact manner in which earth acts against a wall; and they are, therefore, of little value except in determining the general principles on which the stability of these constructions depends.

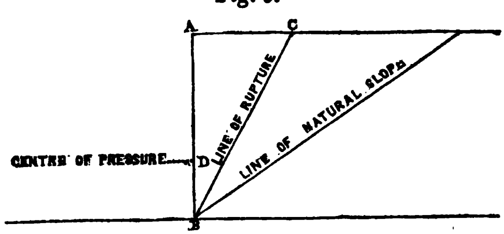
47. The calculation of the stability of a retaining wall divides itself into two parts:

1st. The thrust of the earth to be supported.

2d. The resistance of the wall.

48. Definitions (see fig. 9.)—*The line of rupture* is that along which separation takes place in case of a *slip* of

Fig. 9.



earth. The slope which the earth would assume, if left totally unsupported, is called the *natural slope*, and it has been

found that the line of rupture generally divides the angle formed by the natural slope and the back of the wall into nearly equal parts.

The *centre of pressure* is that point in the back of the wall above and below which there is an equal amount of pressure; and this has been found by experiment and calculation to be at two-thirds of the vertical height of the wall from its top.

The wall is assumed to be a solid mass, incapable of sliding forward, and giving way only by turning over on its front edge as a fulcrum. In the annexed diagrams the foundations of the walls have, in all cases, been omitted, to simplify the subject as much as possible. The term *slope* in the following investigation is used as synonymous with the expression *line of rupture.*

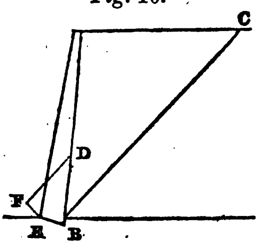
49. *Amount and Direction of the Thrust.*—There are two ways in which this may be calculated:—1st, By considering the earth as a solid mass sliding down an inclined plane, all slipping between the earth and the back of the wall being prevented by friction. This gives the *minimum* thrust of the earth. 2nd, By assuming the particles of earth to have so little cohesion, that there is no friction either on the slope or against the back of the wall. This method of calculation gives the *maximum* thrust.

The real thrust of any bank will probably be somewhere between the two, depending on a variety of conditions which it is impossible to reduce to calculation; for, although we may by actual experiments with sand, gravel, and earths of different kinds, obtain data whence to calculate the thrust exerted by them in a perfectly dry state, another point must be attended to when we attempt to reduce these results to practice, viz., the action of water, which, by destroying the cohesion of the particles of earth, brings the mass of material behind the wall into a semi-fluid state, rendering its action more or less similar to that of a fluid according to the degree of saturation.

The tendency to slip will also very greatly depend on the manner in which the material is *filled* against the wall. If the ground be *benched out* (see fig. 8,) and the earth well punned in layers inclined *from* the wall, the pressure will be very trifling, provided only that attention be paid to surface and back drainage. If, on the other hand, the bank be tipped in the usual manner in layers sloping *towards* the wall, the full pressure of the earth will be exerted against it, and it must be made of corresponding strength.

50. *Calculation of Minimum Thrust.*—The weight of the prism of earth represented by the triangle A B C, fig. 9,

Fig. 10.



will be directly as the breadth A C, the height being constant; and the inclination of B C remaining constant, but the height varying, the weight will be as the square of the height. If, therefore, we call the weight of the prism A B C, W, the breadth A C, b, the height A B, h, and the specific gravity of the earth, s, we shall have $W = \frac{b\,h\,s}{2}$. If we call the thrust of W in the direction of the slope W′, then (neglecting friction,) on the principle of the inclined plane, W will be to W′ as the length of the incline is to its height; or, calling the length B C, l, then

$$l : h :: W : W' = \frac{h\,W}{l} = \frac{b\,h^2\,s^*}{2\,l}.$$

* The value of W′ here given will increase with the length of A C in a constantly decreasing ratio, never exceeding $\frac{h^2 s}{2}$ supposing the back of the wall to be upright. But in practice the friction must always be taken into consideration; and, as this increases directly as A C, there will be a limit at which the thrust and the resistance balance each other, this limit being the natural slope; and, as the thrust and the resistance increase with the length of A C in different ratios, there will be a point at which the effective thrust is greatest, or, in other words, a slope of maximum thrust which determines the position of the line of rupture.

The effect of the weight of the prism A B C to overturn the wall will be as W′ multiplied by the leverage E F, fig. 10, found by letting fall the perpendicular E F, from the front edge of the wall, upon D F, drawn through the centre of pressure in a direction parallel to the slope. When D F passes through E, then $EF = O$, and the thrust has no tendency to overturn the wall; and when D F falls within the base of the wall, E F becomes a negative quantity, the thrust increasing its stability. Calling the overturning thrust T, we have

$$T = W' \times EF = \frac{b h^2 s + EF,}{2 l}$$

the value of E F* depending on the inclination of the slope, and the width of the base of the wall.

51. *Calculation of Maximum Thrust.*—If we consider the moving mass to slide freely down the slope, and the friction between the earth and the back of the wall to be so slight as to be inappreciable, then the prism A B C will act as a wedge, with a pressure perpendicular to the back of the wall, which will be the same whatever the inclination of B C, the height and inclination of the back of the wall being constant, and as the square of the height where the height varies, the pressure being the least when the back of the wall is vertical; for calling the pressure P, and drawing A I, fig. 11, perpendicular to B C, we have, on the principle of the wedge,

$$AI : AB :: W' : P = \frac{W' \times AB}{AI} = \frac{b h^2 s \times AB}{2 l \times AI}$$

and by construction $b h = l\, AI$, as they are each equal to

---

$$* \; EF = \frac{h}{l} \times \left(\frac{b}{3} - EB\right) \text{ and}$$

$$T = W' \times EF = \frac{b\, b^2 s}{2l} \times \frac{h}{l}\left(\frac{b}{3} - EB\right) - \frac{b\, h^3\, s}{2l^2} \times \frac{b}{}\left(\frac{b}{3} - EB\right)$$

twice the area of triangle A B C; therefore, by substitution,

$$P = \frac{l\,A\,I\,h\,s \times A\,B}{2\,l\,A\,I} = \frac{h\,s \times A\,B}{2}.$$

The effect of the prism A B C to overturn the wall will be P multiplied by the leverage E F*, which will be found by drawing D F, fig 13, at right angles to the back of the wall

Fig. 11.

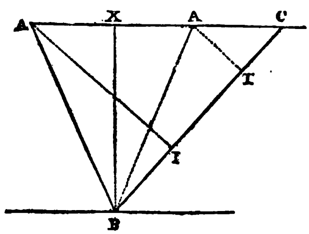
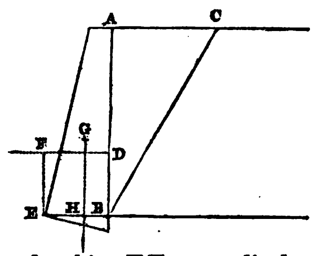


Fig. 12.



through the centre of pressure, and making E F perpendicular to it; then calling the overturning thrust, as before, T,

$$T = P \times E\,F = \frac{A\,B \times h\,s \times E\,F}{2}$$

When D F passes through E, then E F = 0, and the thrust has no tendency to overturn the wall; and, if D F falls within the base, the thrust will *increase* its stability. When the back of the wall is vertical, then

$$A\,B = h \text{ and } E\,F = \frac{h}{3} \text{ and } T = \frac{h^3 s}{6}.$$

---

* Calling the angle X A B = θ

$$E\,F = \frac{A\,B}{3} \mp \frac{E\,B.A\,X}{A\,B} = \frac{h}{3} \text{ cosec. } \theta \mp E\,B \cos.\theta$$

$$\text{And } T = P \times E\,F = \frac{A\,B.h\,s}{2} \times \left(\frac{A\,B}{3} \mp \frac{E\,B.A\,X}{A\,B}\right) = \frac{h\,s}{2} \times \left(\frac{A\,B^2}{3} \mp E\,B.A\,X\right)$$

The positive sign is to be used when the back of the wall leans backwards; the negative, when it leans forwards.

52. These results show that, where the friction of the earth against the slope and the back of the wall is destroyed by the filtration of water, the action of the earth will be precisely similar to that of a column of water of the height of the wall. The pressure upon the side of any vessel is the half of the pressure that would take place upon the bottom if of the same area. Now, calling the specific gravity of the water s, the pressure upon the bottom, supposing its length to be A B, would be $h s$ A B ; therefore the pressure upon the side will be $\frac{h s \text{ A B}}{2}$; and $\text{T} = \text{P} \times \text{E F} = \frac{h s \text{ A B.E F}}{2}$.

And, where the back of the wall is vertical, then

$$\text{A B} = h \text{ and E F} = \frac{h}{3} \text{ as above. Therefore}$$

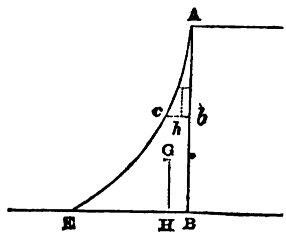
$$\text{P} - \frac{h^2 s}{2} \text{ and } \text{T} = \frac{h^2 s}{2} \times \frac{h}{3} = \frac{h^3 s}{6};$$

which results are precisely the same as those arrived at above.

53. *Resistance of the Wall.*—Considering the wall as a solid mass, the effect of its weight to resist an overturning thrust will be directly as the horizontal distance E H from its front edge to a vertical line drawn through G, the centre of gravity of the wall, fig. 13 ; or, calling the resistance R, and the weight of the wall w, then $\text{R} = w \times \text{E H}$. E H will be directly as E B, the proportions of the wall being constant ; therefore a wall of triangular section will afford more resistance than a rectangular one of equal sectional area, the base of a triangle being twice that of a rectangle of equal height and area.

If the wall be built with a curved concave batter, fig. 14, E H will be still greater than in the case of a triangular wall of equal sectional area ; and, if the wall were one solid

Fig. 13.



mass incapable of fracture, this form would offer more resistance than the triangular. But, as this is not the case, we may consider any portion of the wall cut off from the bottom by a level line to be a distinct wall resting upon the lower part as a foundation. Imagine A *e* *b* to be a complete wall capable of turning upon *e* as a fulcrum. The resistance would be considerably less than that of the corresponding portion of a triangular wall. In the case of a triangular wall, the proportions of the resistance to the thrust will be the same throughout its height. In the case of a rectangular one, the resistance will bear a greater proportion to the thrust, the greater the distance from the bottom. In the case of a wall with a concave curved batter, the reverse of this takes place.

The value of E H will be greatest when E H = E B, the wall will be then exactly balanced on H; but in practice this limit should never be reached, for fear the wall should become crippled by depending on the earth for support. The value of E H will be least when H coincides with E, which opposite limit also is never reached in practice—for obvious reasons—as the wall would in this case overhang its base, and be on the point of falling forward.

54. The increased leverage is not the only advantage gained by the triangular form of wall. In the foregoing investigation, we have considered the wall as a solid mass turning on its front edge. Now, practically, the difficulty is not so much to keep the wall from overturning as to prevent the courses from sliding on each other.

In an upright wall, built in horizontal courses, the chief resistance to sliding arises from the adhesion of the mortar; but, if the wall be built with a sloping or *battering* face, the beds of the courses being inclined to the horizon, the resist-

ance to the thrust of the bank is increased in proportion to the tendency of the courses to slide down towards the bank; thus rendering the adhesion of the mortar merely an additional security. The importance of making the resistance independent of the adhesion of the mortar is obviously very great, as it would otherwise be necessary to delay backing up a wall until the mortar were thoroughly set, which might require several months.

55. The exact determination of the thrust which will be exerted against a wall of given height is not possible in practice; because the thrust depends on the cohesion of the earth, the dryness of the material, the mode of backing up the wall, and other conditions which we have no means of ascertaining. Experience has, however, shown that the base of the wall should not be less than one-fourth, and the batter or slope not less than one-sixth of the vertical height, wherever the case is at all doubtful.

56. The results of the above investigation are illustrated in figures 14, 15, 16, 17, and 18, which show the relative

Fig. 14.

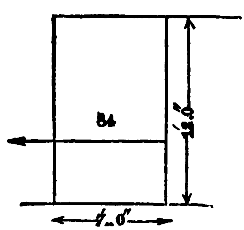
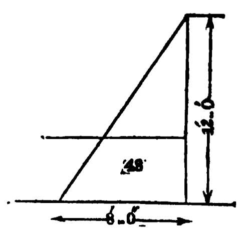


Fig. 15.



sectional areas of walls of different shapes, that would be required to resist the pressure of a bank of earth 12 feet high.

Fig. 16.

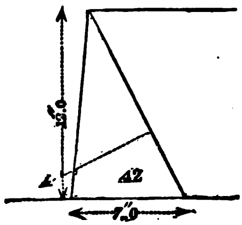


Fig. 17.

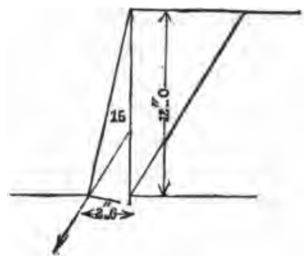
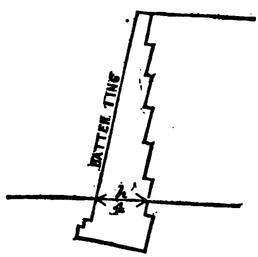


Fig. 18.



The first three examples are calculated to resist the maximum, and the fourth, the minimum, thrust; whilst the last figure shows the modified form usually adopted in practice.

57. It is sometimes necessary in soft ground to protect the *toe* or front edge of a retaining wall with sheet piling, to prevent it from being forced forward; this is shown in fig. 8.

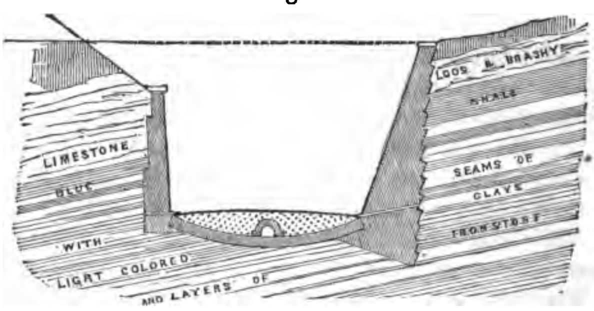
58. *Counterforts.*—Retaining walls are often built with counterforts, or buttresses, at short distances apart, which allow of the general section of the wall being made lighter than would otherwise be the case. The principle on which these counterforts are generally built is, however, very defective, as they are usually placed *behind* the wall, which frequently becomes torn from them by the pressure of the earth. The strength of any retaining wall would, however, be greatly increased were it built as a series of arches, abut-

ting on long and thin buttresses; but the loss of space that would attend this mode of construction has effectually prevented its adoption except in a few instances.

59. *Breast Walls.*—Where the ground to be supported is firm, and the strata are horizontal, the office of a breast wall is more to protect, than to sustain the earth. It should be borne in mind that a trifling force, skilfully applied to unbroken ground, will keep in its place a mass of material which, if once allowed to move, would crush a heavy wall; and, therefore, great care should be taken not to expose the newly opened ground to the influence of air and wet for a moment longer than is requisite for sound work, and to avoid leaving the smallest space for motion between the back of the wall and the ground.

60. The strength of a breast wall must be proportionately increased when the strata to be supported incline *towards* the wall, as in fig. 19: where they incline from it, the wall need be little more than a thin facing to protect the ground from disintegration.

Fig 19.



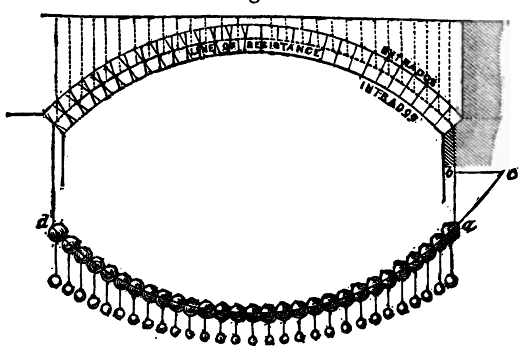
61. The preservation of the natural drainage is one of the most important points to be attended to in the erection of breast walls, as upon this their stability in a great measure depends. No rule can be given for the best manner of doing this; it must be a matter for attentive consideration in each particular case.

ARCHES.

62. An arch in perfect equilibrium may be considered as a slightly elastic curved beam, every part of which is in a state of compression, the pressure arising from the weight of the arch and its superincumbent load being transmitted to the abutments on which it rests in a curved line called the *curve of equilibrium*, passing through the thickness of the arch.

63. The wedge-shaped stones of which a stone arch is composed are called the *voussoirs*. The upper surface of an arch is called its *extrados*, and the lower surface its *intrados* or *soffit* (see fig. 20). Theoretically, a stone arch might

Fig. 20.



give way by the sliding of the voussoirs on each other; but in practice the friction of the material and the adhesion of the mortar is sufficient to prevent this, and failure takes place in the case of an overloaded arch by the voussoirs turning on their edges.

64. The curve of equilibrium will vary with the rise and span of the arch, the depth of the arch stones, and the distribution of the load, but it will always have this property, namely, that the horizontal thrust will be the same at every part of it. In order that an arch may be in perfect equili-

brium, its curvature should coincide with that of the curve of equal horizontal thrust; if, from being improperly designed or unequally loaded, this latter curve approaches either the intrados or the extrados, the voussoirs will be liable to fracture from the pressure being thrown on a very small bearing surface; and if it be not contained within the thickness of the arch, failure will take place by the joints opening, and the voussoirs turning on their edges.

65. The manner in which the curve of equilibrium is affected by any alteration in the load placed upon an arch may readily be seen by making an experimental equilibrated arch with convex voussoirs, as shown in fig. 20. When bearing its own weight only, the points of contact of the voussoirs will lie wholly in the centre of the thickness of the arch; when loaded at the crown, the points of contact will approach the extrados at the crown, and the intrados at the haunches; and, if loaded at the haunches, the reverse effect will take place.

66. If a chain be suspended at two points, and allowed to hang freely between them, the curve it takes is the curve of equilibrium of an arch of the same span and length on soffit, in which the weights of the voussoirs correspond to the weights of the links of the chain, and would be precisely the same as that marked out by the points of contact of the curved voussoirs of an experimental arch of the same dimensions built as above described.

67. In designing an arch, two methods of proceeding present themselves: we may either confine the load to the weight of the arch itself or nearly so, and suit the shape of the arch to a given curve of equilibrium, or we may design the arch as taste or circumstances may dictate, and load it until the line of resistance coincides with the curve thus determined upon.

The Gothic vaults of the middle ages were, in a great measure, constructed on the first of these methods, being in many cases only a few inches in thickness, and the curvature

of the main ribs coinciding very nearly with their curves of equal horizontal thrust. We have no means of ascertaining whether this was the result of calculation or experiment; probably the latter, but the principle was evidently understood.

At the present day, the requirements of modern bridge building often leave the architect little room for choice in the proportions of his arches, or the height and inclinations of the roadway they are to carry; and it becomes necessary to calculate with care the proportion of the load which each part of the arch must sustain, in order that the curve of equilibrium may coincide with the curvature of the arch.

68. The formulæ for calculating the equilibration of an arch are of too intricate a nature to be introduced in these pages; but the principles on which they depend are very simple.

Let it be required to construct a stone arch of a given curvature to support a level roadway, as shown in fig. 20, and to find the weight with which each course of voussoirs must be loaded to bring the arch into equilibrium.

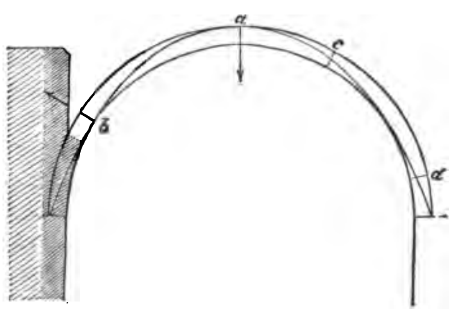
Draw the centre line of the arch to a tolerably large scale in an inverted position on a vertical plane, as a drawing board, for instance, and from its springing points *a*, *d*, suspend a fine silk thread of the length of this centre line strung with balls of diameter and weight corresponding to the thickness and weight of the voussoirs of the arch; then, from the centre of each ball suspend such a weight as will bring the thread to the curve marked on the board, and these weights will represent the load which must be placed over the centre of gravity of each of the voussoirs, as shown by the dotted lines, in order that the arch may be in equilibrium.

To find what will be the thrust at the abutments, or at any point in the arch, draw *a c*, touching the curve, the vertical line *a b* of any convenient length, and the horizontal line *b c*, then the lengths of the lines *a c*, *a b*, and *b c*, will be

respectively as the thrust of the arch at a, in the direction $a\ c$, and the vertical pressure and horizontal thrust into which it is resolved; and the weight of that part of the arch between its centre and the point a, which is represented by $a\ b$, being known, the other forces are readily calculated from it.

69. When the form of an arch does not exactly coincide with its curve of equal horizontal thrust, there will always be some minimum thickness necessary to contain this curve, and to insure the stability of the arch. In a semicircular, fig. 21, whose thickness is one-ninth of its radius, the line of equal horizontal thrust just touches the extrados at the crown, and the intrados at the haunches, pointing out the places where failure would take place with a less thickness or an unequal load, by the voussoirs turning on their edges. Those arches which differ most from their curves of equal horizontal thrust are semicircles and semi-ellipses, which have a tendency to descend at their crowns and to rise at their haunches, unless

Fig. 21.



they are well *backed up*. Pointed arches have a tendency to *rise* at the crown; and, to prevent this, the cross springers of the ribbed vaults of the middle ages were often made of a semicircular profile, their flatness at the crown being concealed by the bosses at their intersections.

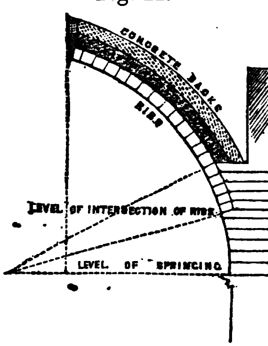
70. If the experiment be tried of equilibrating, in the manner above described, a suspended semicircular or semi-

elliptical arch, it will be found to be practically impossible, as the weight required for that purpose becomes infinite at the springing. This difficulty does not exist in practice, for that part of an arch which lies beyond the plane of the face of the abutment in reality forms a part of the abutment itself (fig. 21).

The Gothic architects well understood this, and in their vaulted roofs built this portion in horizontal courses as part of the side walls (fig. 22), commencing the real arch at a point considerably above the spinging.

71. The depth of the voussoirs in any arch must be sufficient to contain the curve of equilibrium under the greatest load to which it can be exposed; and, as the pressure on the arch stones increases from the crown to the springing, their depth should be increased in the same proportion. Each joint of the voussoirs should be at right angles to a tangent to the curve of equilibrium at the point throught which it passes.

Fig. 22.*



72. *Brick Arches.*—In building arches with bricks of the common shape, which are of the same thickness throughout their length, a difficulty arises from the thickness of the mortar joints at the extrados being greater than at the intrados, thus causing settlement and sometimes total failure. To obviate this difficulty, it is usual to build brick arches in separate rings of the thickness of half a brick, having no connection with each other beyond the adhesion of the mortar or cement, except an occasional course of headings where the joints of two rings happen to coincide. There is, how-

* This diagram is slightly altered from one of the illustrations to Professor Willis's paper "On the Construction of the Vaults of the Middle Ages," in the Transactions of the Royal Institute of British Architects, Vol. I., Part 2.

ever, a strong objection to this plan, viz., that, if the curve of equal horizontal thrust do not coincide with the curvature of the arch, the line of pressure will cross the rings, and cause them to separate from each other.

73. The preferable plan will be, therefore, to bond the brick-work throughout the whole thickness of the arch, using either cement or hard-setting mortar, which will render the thickness of the joints of comparatively little importance.

Cement, however, is not so well suited for this purpose as the hard setting mortars made from the Lias limes, because it sets before the work can be completed; and in case of any settlement, however trifling, taking place on the striking of the centres, the work becomes crippled. It is therefore preferable to use some hard setting mortar, which does not, however, set so quickly as cement, thus allowing the arch to adjust itself to its load, or, in technical language, to *take its bearing*, before the mortar becomes perfectly hard.

72. We have in the preceding remarks considered an equilibrated arch as a curved beam, every part of which is in a state of compression; and, in an arch composed of stone voussoirs, this is practically the case.

We may, however, by the employment of other materials, as cast iron and timber, construct arches whose forms differ very materially from their curves of equal horizontal thrust.

Thus the semicircular arch (fig. 21,) which, if built of stone voussoirs small in proportion to the span of the arch, would fail by the opening of the joints at *a* and *b*, might be safely constructed with cast-iron ribs, with the joints placed at *c* and *d*, the metal at the points *a* and *b* being exposed to a cross-strain precisely similar to that of a horizontal beam loaded in the centre.

73. Laminated arched beams, formed of planks bent round a mould to the required curve and bolted together, have been extensively used in railway bridges of large span during the last ten years, and from their comparative elasticity, and the resistance they offer to both tension and com-

pression, are very well adapted to structures of this kind, which have to sustain very heavy loads passing with great rapidity over them.

It is to be regretted, however, that the perishable nature of the material does not warrant their long duration, notwithstanding every precaution that can be taken for the preservation of the timber.

74. *Skew Arches.*—In ordinary cases the plan of an arch is rectangular, the faces of the abutments being at right angles to the fronts; but of late years the necessity which has arisen on railway works of carrying communications across each other without regard to the angle of their intersection, has led to the construction of oblique or *skew* arches.

75. In an ordinary rectangular arch each course is parallel to the abutments, and the inclination of any bed joint with the horizon will be the same at every part of it. In a skew arch it is not possible to lay the courses parallel to the abutments, for, were this done, the thrust being at right angles to the direction of the courses, a great portion of the arch on each side would have nothing to keep it from falling. In order to bring the thrust into the right direction, the courses must therefore be laid as nearly as possible at right angles to the fronts of the arch (see fig. 23,) and at an angle with the abutments; and it is this which produces the peculiarity of the skew arch. The two ends of any course will then be at different heights, and the inclination of each bed joint with the horizon will increase from the springing to the crown, causing the beds to be *winding surfaces* instead of a series of planes, as in a rectangular arch. The variation in the inclination of the bed joints is called the *twist* of the beds, and leads to many difficult problems in stone-cutting, the consideration of which

Fig. 23.

would be unsuited to the elementary character of this little work.

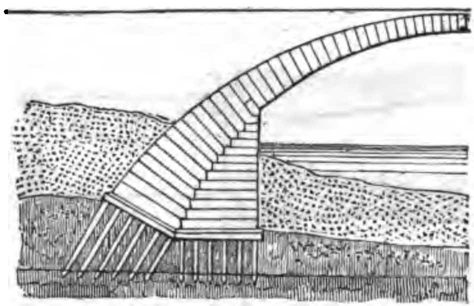
76. *Centering.*—The *centering* of an arch is the temporary framework which supports it during its erection, and is formed of a number of ribs or *centres*, on which are placed the planks or *laggings* on which the work is built.

77. In designing centres, there are three essential points to be kept in view. 1st, that there should be sufficient strength to prevent any settlement or change of form during the erection of the arch. 2d, that means should be provided for *easing* or lowering the centre gradually from under any part of the arch. 3d, that, as the construction of centres generally involves the use of a large quantity of timber merely for a temporary purpose, all unnecessary injury to it should be avoided, in order that its value for subsequent use may be as little diminished as possible.

78. Where the circumstances of the case do not admit of piles or other supports being placed between the piers, it becomes necessary to construct a trussed framing resting on the piers, and of sufficient strength to support the weight of the arch. The tendency of this form of centre to rise at the crown, from the great pressure thrown upon the haunches during the erection of the arch, renders it necessary to weight the crowns with blocks of stone until it is nearly completed. Centres of this kind are always costly, and afford little facilities for easing.

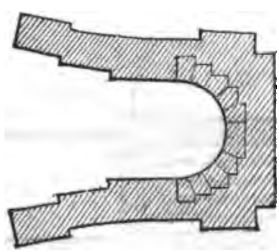
79. *Abutments.*—The tendency of any arch to overturn its abutments, or to destroy them by causing the courses to slide over each other, may be counteracted in three ways. 1st, the arch may be continued through the abutment until it rests on solid foundation, as in fig. 24. 2d, by building the abutments so as to form a horizontal arch, the thrust

Fig. 24.



being thrown on the wing walls, which act as buttresses (fig. 24.) 3d, where neither of these expedients

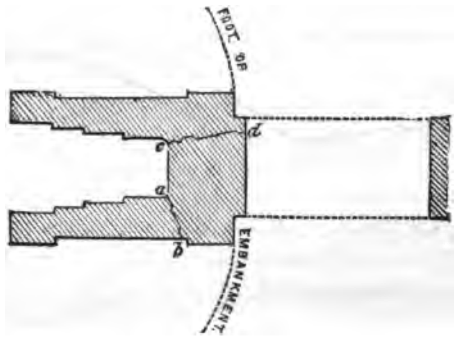
Fig. 25.



is practicable, by joggling the courses together with bed-dowel joggles, so as to render the whole abutment one solid mass.

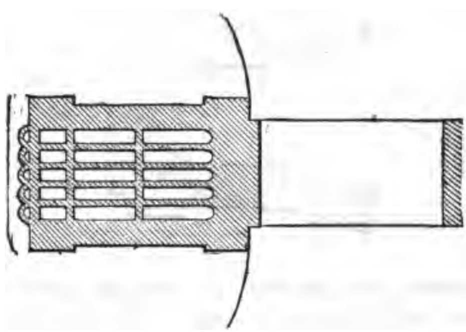
80. *Wing Walls.*—Where the wing walls of a bridge are built as shown in fig. 26, the pressure of the earth will always have a tendency to fracture them at their junction

Fig. 26.



with the abutments, as shown by the lines *a b*, *c d*. Equal strength with the same amount of material will be obtained by building a number of thin longitudinal and cross walls, as shown in fig. 27, by which means, the earth being kept from

Fig. 27.



the back of the walls, there is no tendency to failure of this kind.

81. *Vaulting.*—The ordinary forms of vaults may be classed under three heads, viz., *cylindrical*, *coved*, and *groined*.

A *cylindrical* vault is simply a semicircular arch, the ends of which are closed by upright walls, as shown in fig. 28.

When a vault springs from all the sides of its plan, as in fig. 29, it is said to be *coved*. When two cylindrical vaults in-

Fig. 28.

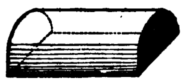
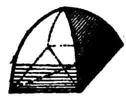


Fig. 29.

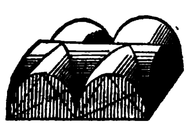


tersect each other, as in fig. 30, the intersections of the vaulting surfaces are called *groins*, and the vault is said to be *groined*.

82. In the Roman style of architecture, and in all common vaulting, the vaulted surfaces of the several compartments are portions of a continuous cylindrical surface, and the profile of a groin is simply an oblique section of a semi-cylinder.

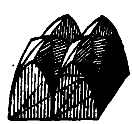
83. Gothic ribbed vaulting is, however, constructed on a totally different principle. It consists of a framework of light stone ribs supporting thin panels, whence this mode of construction has obtained the name of *rib and pannel* vaulting. The curvature of the diagonal ribs or cross springers, and of the intermediate ribs, is not governed in any way by the form of the transverse section of the vault, and in this consists the peculiarity of ribbed vaulting. This will be understood by a comparison of figs. 30 and 31.

Fig. 30.



Roman vaulting.

Fig. 31.



Gothic vaulting.

84. Domes are vaults on a circular plan. The equilibrium of a dome depends on the same conditions as that of a common arch, but with this difference, that, although a dome may give way by the weight of the crown forcing out the haunches, failure by the weight of the haunches squeez-

ing up the crown is impossible, on account of the support the voussoirs of each course receive from each other.

MASONRY—BRICKWORK—BOND.

85. The term *masonry* is sometimes applied generally to all cemented constructions, whether built of brick or stone; but generally the use of the term is confined exclusively to stone-work.

86. There are many kinds of masonry, each of which is known by some technical term expressive of the manner in which the stone is worked; but they may all be divided under three heads.

1st. Rubble work (fig. 32,) in which the stones are used without being squared.

2nd. Coursed work (fig. 33,) in which the stones are squared, more or less, sorted into sizes, and ranged in courses.

Fig. 32.

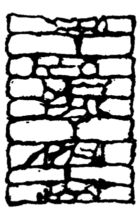


Fig. 33.

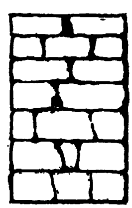
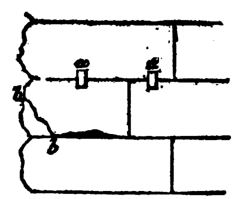


Fig. 34.



3d. Ashlar work* (fig. 34), in which each stone is squared and dressed to given dimensions.

87. Different kinds of masonry are often united. Thus a wall may be built with ashlar facing and rubble backing; and there are many gradations from one class of masonry to another, as *coursed rubble*, which is an intermediate step between rubble work and coursed work.

88. In ashlar masonry, the stability of the work is

* In London. the term "ashlar" is commonly applied to a thin facing of stone placed in front of brickwork.

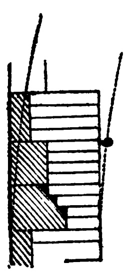
independent, in ordinary cases, of the adhesion of the mortar. Rubble work, on the contrary, depends for support in a great measure upon it.

89. In dressing the beds of ashlar work, care must be taken not to work them hollow, so as to throw the pressure upon the edges of the stones, as this leads to unsightly fractures, as *b b*, fig. 34.

90. Where there is a tendency of the courses to slide on each other from any lateral pressure, it may be prevented by bed-dowel joggles, as shown at *a a*, fig. 34.

91. Where the facing and the backing of a wall do not contain the same number of courses, as in the case of a brick wall with stone facings (fig. 35) the work will be liable to settle on the inside, as shown by the dotted lines, from the greater number of mortar joints. The only way of preventing this is to set the backing in cement, or some hard and quick-setting mortar.

Fig. 35.

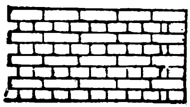


92. In facing brickwork with stone ashlar, the stones should be all truly squared, and worked to sizes that will bond with the brickwork. If this be neglected, there will be numerous vacuities in the thickness of the wall (see fig. 35), and the facing and backing will have a tendency to separate.

93. *Bond*, in masonry, consists in the placing of the stones in such relative positions that no joint in any course shall be in the same plane with any other joint in the course immediately above or below it. This is called *breaking joint.*

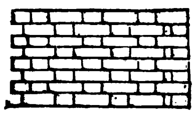
94. Stones placed lengthwise in any work are called *stretchers*, and those placed in a contrary direction are

Fig. 36.



English Bond.

Fig. 37.



Flemish Bond.

called *headers*. When a header extends throughout the whole thickness of a wall, it is called a *through*.

95. There are two kinds of bond made use of by bricklayers, called respectively *English bond* and *Flemish bond*. In the first the courses are laid alternately with headers and stretchers (fig. 36); in the second, the headers and stretchers alternate in the same course (fig. 37). This is considered to have the neatest appearance: but, as the number of headers required is fewer than in English bond, there is not so much lateral tie, and on this account it is considered to be much inferior to it in strength. A common practice, which cannot be too much reprobated, is that of building brick walls with two qualities of bricks, without any bond between them, the headers of the facing bricks being cut in two to save the better material, thus leaving an upright joint between the facing and backing.

95. In building upright walls, which have to sustain a vertical pressure, three leading principles must be kept in view.

1. Uniformity of construction throughout the whole thickness.

2. The bonding of the work together.

3. The proper distribution of the load.

96. *Uniformity of Construction.*—We have already spoken of the danger arising from the backing of a wall containing more compressible material than the facing; but it cannot be too often repeated, that in all building operations it is not the *amount*, but *irregularity* of settlement which is so dangerous. Thus a rubble wall, with proper care, may be carried up to a great height, and bear safely the weight of the floors and roof of a large building, whilst a wall built of bricks

and mortar, and faced with dressed ashlar, will, under similar circumstances, be fractured from top to bottom, from the difference in settlement of the facing and backing.

It is a common but vicious practice to build the ends of joists and other timbers into the walls, and to rest the superincumbent work upon them. This is liable to lead to settlements from the shrinking of the timber, and should always be guarded against by leaving proper recesses for the ends of the timbers, so that the strength of the masonry or brick-work shall be quite independent of any support from them.

97. *Bond.*—In addition to the bonding together of the materials above described, a further security against irregular settlement is usually provided for brick walls, in the shape of ties of timber, called *bond*, which are cut of the depth and thickness of a brick, and built into the work. There is, however, a great objection to the use of timber in the construction of a wall, as it shrinks away from the rest of the work, and often endangers its stability by rotting.

98. Instead of bond timbers, hoop-iron bond is now very generally used. This is formed of iron hooping, tarred, to protect the iron from contact with the mortar, and laid in the thickness of the mortar joints. This forms a very perfect longitudinal tie, and has all the advantages, with none of the disadvantages, of bond timbers.

99. *Distribution of the Load.*—It is always advisable, when a heavy load has to be supported on a few points, as in the case of a larger floor resting on girders, to bring the weight as nearly as possible on the centre of the wall, and to distribute it over a large bearing surface, by stone bonding through its whole thickness ; this arrangement is shown in figures 38 and 39.

Fig. 38.

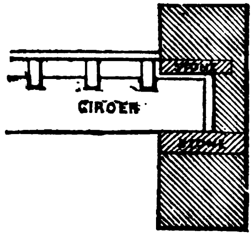
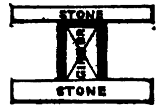


Fig. 39.



100. It is of importance in designing buildings to arrange the apertures for doors, windows, &c., in the different floors, so that openings shall be over openings, and piers over piers; if this be not attended to, it is scarcely possible to prevent settlements. In addition to this, as the pressure on the foundations will be greatest under the piers, it is desirable to connect these with inverted arches, by which means the weight is distributed equally over the whole surface of the foundations.

101. All openings in walls for doors, windows, gate-ways, &c., should be arched over throughout the whole thickness of the walls in which they occur; and wooden lintels and bressummers should only be introduced as ties to counteract the thrust of the arches, and as attachments for the internal finishings.

102. Bressummers of cast iron are often used for supporting the walls of houses over large openings, as in the case of shop fronts; but they have the disadvantage of being liable to be cracked, in case of fire, if water is thrown on them whilst in a heated state, which renders their use very objectionable, as no dependence can be placed upon them after having been suddenly cooled in this manner, even if they do not actually break at the time.

PARTITIONS.

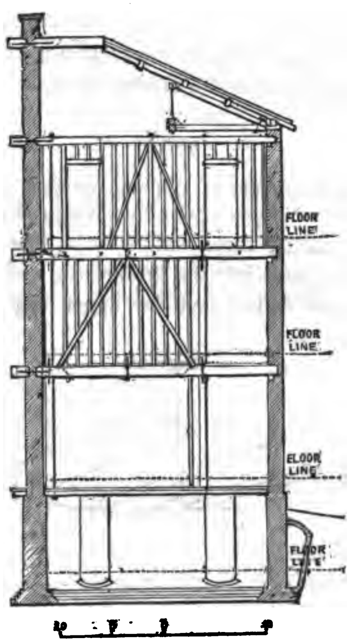
103. The partitions forming the interior divisions of a building may be either solid walling of brick or stone, or

they may be constructed entirely of timber, or they may be frames of timber filled in with masonry or brick-work.

It will always be best, both for durability and security against fire, to make the partitions of solid walling; but this is not always practicable, and, in the erection of dwelling houses, they are for the most part made of timber.

The principles to be kept in view in the construction of framed timber partitions are very simple. Care must be taken to avoid any settlement from cross strain, and they should not in any way depend for support upon subordinate parts of the construction, but should form a portion of the main

Fig. 40.



carcase of the building, and be quite independent of the floors, which should not support, but should be supported by them.

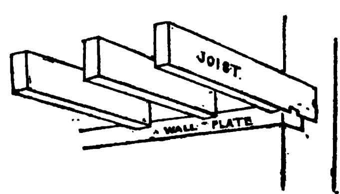
Where a partition extends through two or more stories of a building, it should be as much as possible a continuous piece of framing, with strong sills at proper heights to support the floor joists.

Where openings occur, as for folding doors, or where a partition rests on the ends of the sill only, it should be strongly trussed, so that it is as incapable of settlement as the walls themselves. From want of attention to these points, we frequently see in dwelling-houses floors which have sunk into curved lines, doors out of square, cracked ceilings and broken cornices, and gutters that only serve to conduct the roof water to the interior of the building, to the injury of ceilings and walls, and the great discomfort of its inmates. The above remarks will be better understood by a study of fig. 40, which is an example of a framed partition extending through three stories of a dwelling house.

FLOORS.

104. The assemblage of timbers forming any *naked flooring* may be either *single* or *double*. Single flooring is formed with joists reaching from wall to wall, where they rest on *plates* of timber built into the brick-work, as in fig. 41. The floor boards are nailed over the upper edges of the joists,

Fig. 41.

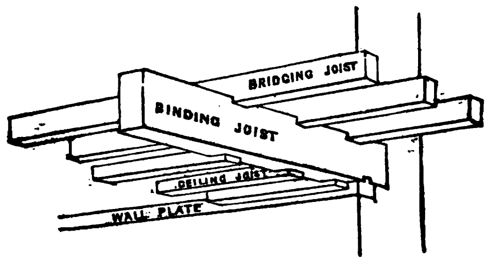


Single flooring.

whose lower edges receive the lathing and plastering of the ceilings. Double floors are constructed with stout *binding joists*, a few feet apart, reaching from wall to wall, and sup

porting *ceiling joists* which carry the ceiling; and *bridging joists*, on which are nailed the floor boards (fig. 42.)

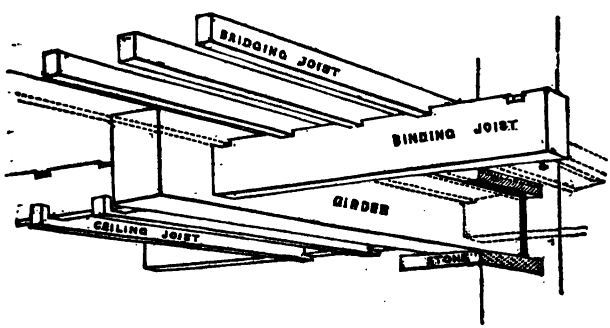
Fig. 42.



Double flooring.

In *double-fram d flooring*, the binders, instead of resting in the walls, ar supported on *girders*, as shown in fig. 43. Single flooring is, in many respects, inferior to double floor-

Fig. 43.



Double-framed flooring.

ing, being liable to *sag*, or deflect, so as to make the floor concave; and the vibration of the joists occasions injury to the ceilings, and also shakes the walls. In double flooring the stiffness of the binders and girders prevents both deflection and vibration, and the floors and ceilings *hold their lines*, that is, retain their intended form much better than in single flooring.

105. The joists in a single floor are usually laid on a plate built into the wall, as shown in fig. 41 ; it is, however, preferable to rest the plate on projecting corbels, which prevents the wall being crippled in any way, by the insertion of the joists. The plates of basement floors are best supported on small piers carried up from the footings. This is an important point to be attended to, as the introduction of timber into a wall is nowhere likely to be productive of such injurious effects as at the foundations, where, from damp and imperfect ventilation, all wood-work is liable to speedy decay.

The ends of all girders should rest in recesses, formed as shown in figs. 38 and 39, and with a space for the free circulation of air round the timber, which is one of the best preventives of decay.

The manner in which ceiling joists and bridging joists are framed to the binders, and these latter tenoned into the girders, is shown in figs. 44, 45, 46, and 47.

Fig. 44.

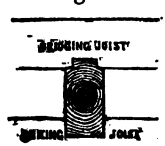


Fig. 45.

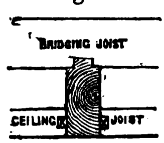


Fig. 46.

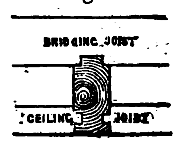
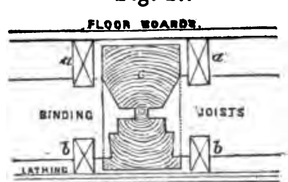


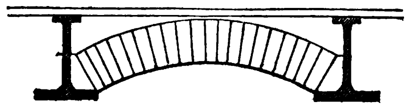
Fig. 47.



a a, bridging joists ; *b b*, ceiling joists ; *c*, girder

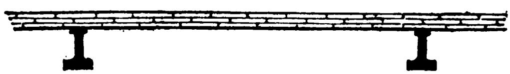
106. Fire-proof floors are usually constructed with iron girders a short distance apart, which serve as abutments for a series of brick arches, on which either a wooden or plaster floor may be laid (see fig. 48).

Fig. 48.



107. Of late years many terraces and flat roofs have been constructed with two or more courses of plain tiles, set in cement, and breaking joint with each other, supported at short intervals by cast-iron bearers, as shown in fig. 49.

Fig. 49.



This mode of construction, although appearing very slight, possesses great strength, and is now very much used in and about London, and in some portions of the United States.

ROOFING.

108. In roofs of the ordinary construction, the roof covering is laid upon *rafters* supported by horizontal *purlins*, which rest on upright *trusses* or frames of timber, placed on the walls at regular distances from each other. Upon the framing of the trusses depends the stability of the roof, the arrangement of the rafters and purlins being subordinate matters of detail. The timbering of a roof may be compared to that of a double-framed floor, the trusses of the former corresponding to the girders of the latter, the purlins to the binders, and the rafters to the joists.

Timber roofs may be divided under two heads—

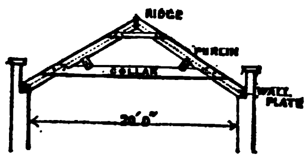
1st. Those which exert merely a vertical pressure on the walls on which they rest.

2d. Those in which advantage is taken of the strength of the walls to resist a side thrust, as in many of the Gothic open timbered roofs.

109. *Trussed Roofs, exerting no Side Thrust on the Walls.* —In roofs of this kind each truss consists essentially of a pair of principal rafters or *principals*, and a horizontal *tie beam*, and in large roofs these are connected and strengthened by *king and queen posts* and *struts* (see figs. 51. and 52).

Fig. 50 shows a very simple truss in which the tie is above the bottom of the feet of the principals, which is often done

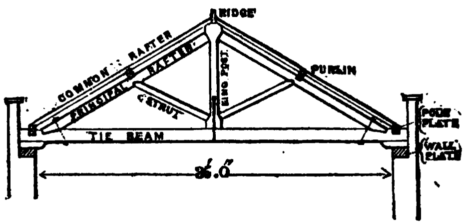
Fig. 50.



in small roofs for the sake of obtaining height. The tie in this case is called a *collar*. The feet of both common and principal rafters rest on a *wall plate*. The purlins rest on the collar, and the common rafters but against a *ridge* running along the top of the roof. This kind of truss is only suited to very small spans, as there is a cross strain on that part of the principals below the collar, which is rendered harmless in a small span by the extra strength of the principals, but which in a large one would be very likely to thrust out the walls.

110. In roofs of larger span the tie beam is placed below the feet of the principals, which are tenoned into, and bolted to it. To keep the beam from *sagging*, or bending by its own weight, it is suspended from the head of the principals by a king post of wood or iron. The lower part of the king post affords abutments for struts supporting the principals immediately under the purlins, so that no cross strain is exerted on any of the timbers in the truss, but they all act in the direction of their length, the principals and struts being subjected to compression, and the king post and tie beam to tension. Fig. 51 shows a sketch of a king truss. The com-

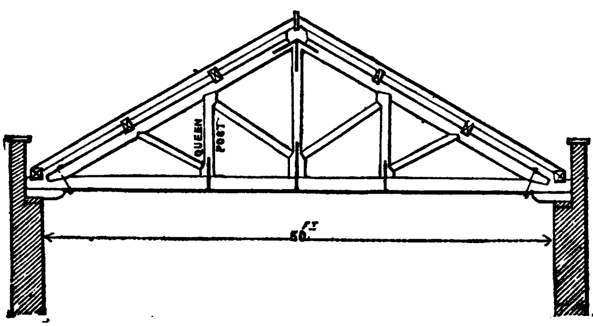
Fig. 51.



mon rafters but on a *pole plate*, the tie beams resting either on a continuous plate, or on short templates of wood or stone.

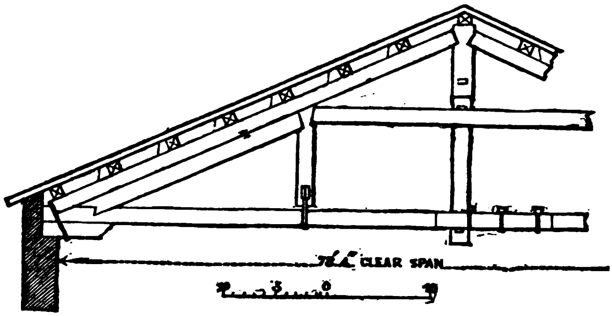
111. Where the span is considerable, the tie beam is supported at additional points by suspension pieces called queen posts (fig. 52), from the bottom of which spring additional

Fig. 52.



struts; and, by extending this principle *ad infinitum*, we might construct a roof of any span, were it not that a practical limit is imposed by the nature of the materials. Sometimes roofs are constructed without king posts, the queen posts being kept apart by a straining piece. This construction is shown in fig. 53, which shows the design of the old

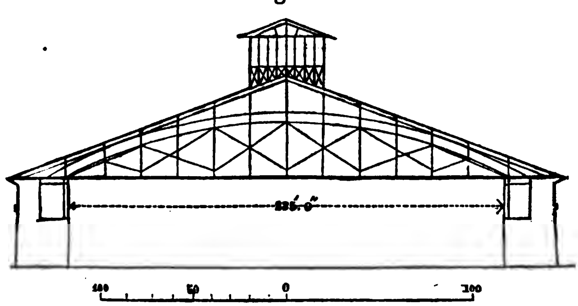
Fig. 53.



roof (now destroyed) of the church of St. Paul, outside the walls, at Rome. This truss is interesting from its early date, having been erected about 400 years ago ; the trusses are in pairs, a king post being keyed in between each pair to support the tie beams in the centre.

112. Of late years iron has been much used as a material for the trusses of roofs, the tie beams and suspending pieces being formed of light rods, and the principals and struts of rolled T or angle iron, to which sockets are riveted to receive the purlins.

Fig. 54.



113. The largest roof ever executed in one span is that of the Imperial Riding House at Moscow, built in 1790, of which the span is 235 ft. (fig. 54). The principal feature in

this roof is an arched beam, the ends of which are kept from spreading by a tie beam, the two being firmly connected by suspension pieces and diagonal braces: the arched beam (fig. 55). is formed of three thicknesses of timber, notched

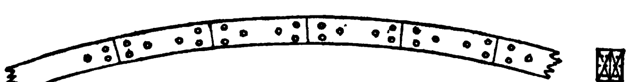
Fig. 55.

out to prevent their sliding on each other,—a method which is objectionable on account of the danger of the splitting of the timber under a considerable strain.

114. The principle of the *bow suspension truss*, as this system of trussing is called, has been much used within the last ten years for railway bridges and similar works. One of the best executed works of this kind is a bridge over the River Ouse, near Downham Market, in Norfolk, on the line of the Lynn and Ely Railway, the trusses of which are 150 ft. span.

115. *Roofs on the principle of the Arch.*—In the 16th century, Philibert de Lorme, a celebrated French architect, published a work, in which he proposed to construct roofs and domes with a series of arched timber ribs in place of trusses, these ribs being formed of planks in short lengths, placed edgewise, and bolted together in thicknesses, breaking joint (fig. 56). This mode of construction has been more or less used ever since the time of its author. An instance of its successful application on a large scale was the original dome of the Halle au Blé, at Paris, 120 ft. in diameter, built by Messrs. Legrand and Molino. This roof has since been

Fig. 56.

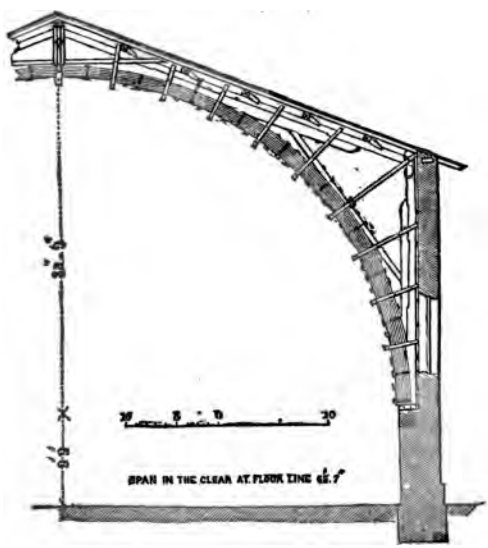


replaced by an iron one, the original dome having been destroyed by fire.

116. There are, however, some great disadvantages, connected with this system. There is considerable waste of material; the labor is great as compared with roofs of similar span of the ordinary construction; and, as the chief strength of the rib depends upon the lateral cohesion of the fibres of the wood, it is necessary to provide such an amount of surplus strength as shall insure it against the greatest cross strain to which it can be exposed from violent winds or otherwise.

117. Struck by these disadvantages, Colonel Emy, a French military engineer, proposed, in 1817, an improvement on the system of Philibert de Lorme, which was precisely the laminated arched rib so much in use at the present day. It was not until 1825 that he obtained permission to put his design into execution in the erection of a large roof 65 ft. span at Marac, near Bayonne (fig. 57). The ribs in

Fig. 57.



this roof are formed of planks bent round on templets to the proper curve, and kept from separating by iron straps, and also by the radiating struts which are in pairs, notched out so as to clip the rib between them.

The principle of the roof is exceedingly good. The principals, wall-posts, and arched rib, form two triangles, firmly braced together, and exerting no *thrust* on the walls ; and the weight of the whole roof being thrown on the walls at the feet of the ribs, and not at the pole plate, the walls are not tried by the action of a heavy roof, and the consequent saving in masonry is very great.

The great difference in principle between the arched rib of Philibert de Lorme, and the laminated rib of Colonel Emy is, that in the latter the direction of the fibre of the wood coincides with the curvature of the rib ; and, as a consequence of this, the joints are much fewer ; the rib possesses considerable elasticity, so as slightly to yield rather than break under any violent strain ; and, from the manner in which the planks are bolted together, it is impossible for the rib to give way, unless the force applied be sufficient to crush the fibres.

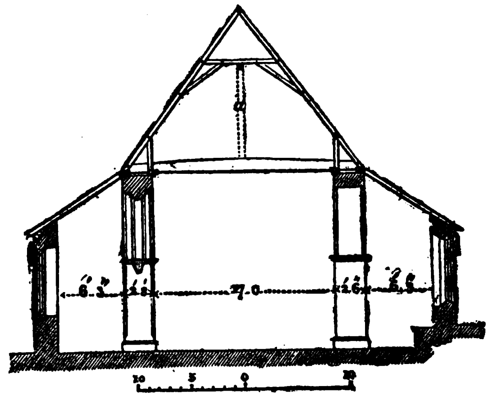
The principle of the laminated arched rib has been extensively used in the erection of railway bridges in England.

118. *Gothic Roofs.*—The open timber roofs of the middle ages come, for the most part, under the second class, viz., those which exert more or less thrust upon the walls, although there are many fine examples in which this is not the case.

We propose to describe the principal varieties of these roofs, without reference either to their decorative details, or to their chronological arrangement, our object here being simply to explain the principles on which they were constructed.

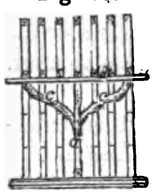
119. Fig. 58, which is a section of the parish church of Chaldon, near Merstham in Surrey, shows a system of roofing formerly very common. This may be compared to single

Fig. 58.



flooring, as there are no principals, purlins, or even ridge. It is a defective form of roof, as the rafters have a tendency to spread and thrust out the walls. In the example before us, this effect has been prevented by the insertion of tie-beams, from which the collars have been propped up (fig. 59), thus, in fact, balancing the roof on the centres of the collars, which are in consequence violently strained.

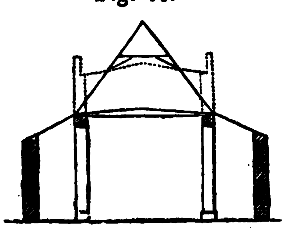
Fig. 59.



a post; *b* sill; *c c* struts.

120. After the introduction of the four-centered arch, a great many church roofs of the construction just described were altered, as shown by the dotted lines in fig. 60, in order to obtain more light by the introduction of clerestory windows over the nave arches. The flat roofs, which superseded the former ones, were often formed without any truss whatever, being simply an arrangement of main beams, purlins, and rafters, precisely similar to a double-framed floor, with the

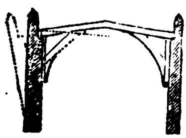
Fig. 60.



difference only that the main beams, instead of being perfectly straight, were usually cut out of crooked timber so as to divide the roof into two inclined planes.

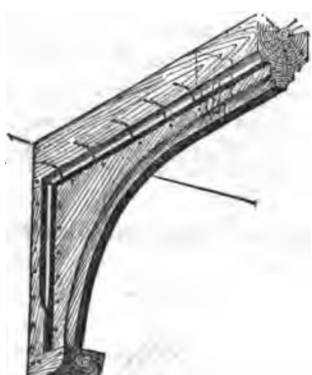
To throw the weight of the roof as low down as possible, the ends of the main beams are often supported on upright posts placed against the walls and resting on projecting corbels, the wall posts and beams being connected by struts in such a way that deflection in the centre of the beam cannot take place, unless the load be sufficient to force out the walls, as shown by the dotted lines in fig. 61

Fig. 61.



The struts are often cut out of stout plank, forming solid spandrils, the edges of which are moulded to suit the profile of the main beam (see fig. 62), which also shows the manner of securing the struts to the wall posts and to the beam with *tongues* and wooden pins.

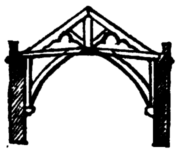
Fig. 62.



121. Fig. 63 exhibits a construction often to be met with, which, in general appearance, resembles a trussed king post roof, but which is in reality very different, the tie beam being a strong girder supporting the king post, which, in-

stead of serving to suspend the tie-beam from the principals, is a prop to the latter. In this and the previous example, any tending to deflection of the tie-beam is prevented by struts: the weight of the roof is thrown by means of wall posts considerably below the feet of the rafters, so that the weight of the upper part of the wall is made available to resist the thrust of the struts.

Fig. 63.

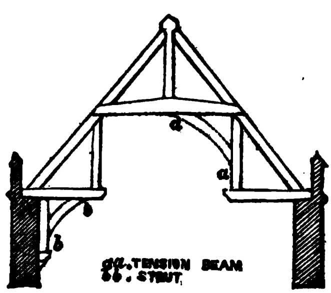


122. The roofs we have been describing are not to be recommended as displaying any great amount of constructive skill. Indeed, although they answer very well for small spans with timbers of large scantling and side walls of sufficient thickness to resist a considerable thrust, they are totally unsuited to large spans, and are in every way inferior to trussed roofs.

The above remarks do not apply to the high pitched roofs of the large halls of the fifteenth and sixteenth centuries, which, for the most part, are trussed in a very perfect manner, so as to exert no thrust upon the walls; although, in some instances, as at Westminster Hall, they depend upon the latter for support.

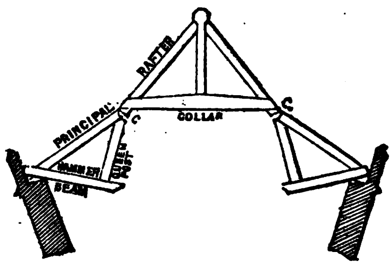
The general design of these roofs is shown in figs. 64 and

Fig 64.



65. The essential parts of each truss are, a pair of principals connected by a collar or *wind beam*, and two *hammer beams*, with queen posts over them, the whole forming three triangles, which, if not secured in their relative positions, otherwise than by the mere transverse strength of the principals, would turn on the points *c c* (fig. 65), the weight of the roof thrusting out the walls in the manner shown in the figure. There are two ways in which a truss of this kind

Fig. 65.

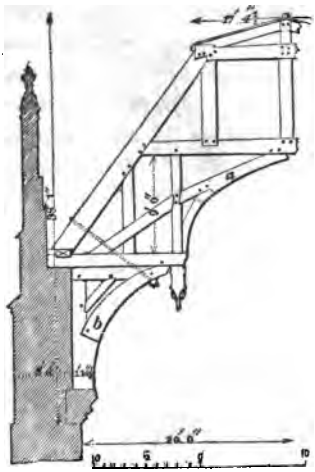


may be prevented from spreading. 1st, The ends of the hammer beams may be connected with the collar by tension pieces, *a a* (fig. 64), by which the thrust on the walls will be converted into a vertical pressure. 2d, The hammer beams may be kept in their places by struts, *b b*, the walls being made sufficiently strong by buttresses, or otherwise, to resist the thrust.

In existing examples, we find sometimes one and sometimes the other of these plans followed; and occasionally both methods are combined in such a manner that it is often difficult to say what parts are in a state of compression, and what are in a state of tension.

123. The roof of the great hall at Hampton Court (fig. 66) is very strong, and so securely tied, that were the

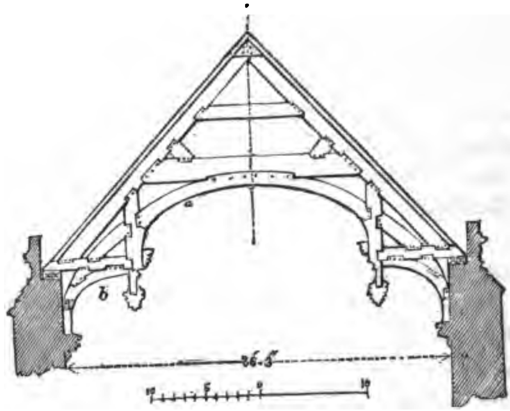
Fig. 66



bottom struts, *b b*, removed, there would be little danger of the principals thrusting out the walls; and, on the other hand, from the weight of the roof being carried down to a considerable distance below the hammer beams by the wall posts, the walls themselves offer so much resistance to side thrust, that there would be no injurious strain on them were the tension pieces, *a a*, removed.

124. The construction of the roof of the hall at Eltham Palace, Kent (fig. 67), differs very considerably from that

Fig. 67.

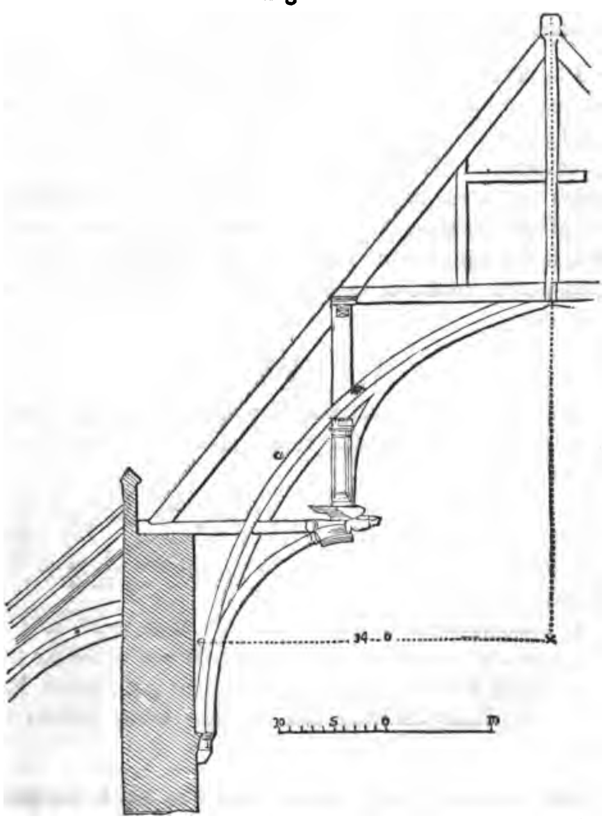


of the Hampton Court roof. The whole weight is thrown on the top of the wall, and the bottom pieces, *b b*, are merely ornamental, the tension pieces, *a a*, forming a complete tie.

This has been shown by a partial failure which has taken place. The wall plates having become rotten in consequence of the gutters being stripped of their lead, the weight has been thrown on the pseudo struts, which have bent under the pressure, and forced out the upper portion of the walls.

125. The roof of Westminster Hall (fig. 68) is one of the finest examples now existing of open timbered roofs. The

Fig. 68.



peculiar feature of this roof is an arched rib in three thick-

nesses, something on the principle of Philibert de Lorme; but it is so slight, compared with the great span, that it is probable, in designing the roof, the architect took full advantage of the support afforded by the thickness of the walls and the buttresses; if, indeed, the latter were not added at the time the present roof was erected, in 1395. It has been ascertained that the weight of the roof rests on the top of the walls, the lower part of the arched rib only serving to distribute the thrust, and to assist in preventing the hammer beams from sliding on the walls.

126. The mediæval architects generally employed oak in the construction of their large roofs, the timbers being morticed and pinned together, as shown in fig. 62. This system of construction is impossible in fir and other soft woods, in which the fibres have little lateral cohesion, as the timber would split with the strain; and therefore, in modern practice, it is usual to secure the connections with iron straps or bolts passing round or through the whole thickness of the timbers.

ROOF COVERINGS.

127. The different varieties of roof coverings principally used may be classed under three heads: stone, wood, and metal.

Of the first class, the best kind is slate, which is used either sawn into slabs or split into thin laminæ. The different sizes of roofing slate in common use are given in the description of Slaters' Work.

In many parts of England, thin slabs of stone are used in the same way as roofing slate. In the Weald of Sussex the stone found in the locality is much used for this purpose, but it makes a heavy covering, and requires strong timbers to support it.

128. *Tiles* are of two kinds: *plain tiles*, which are quite flat; and *pantiles*, which are of a curved shape, and lap over

each other at the sides. Each tile has a projecting ear on its upper edge, by which it is kept in its place. Sometimes plain tiles are pierced with two holes, through which oak pins are thrust for the same purpose.

129. Wooden coverings are little used at the present day, except for temporary purposes; *shingles* of split oak were formerly much used, and may still be seen on the roofs of some country churches. Cedar shingles are much used.

130. *Metallic Coverings.*—The metals used for roof coverings are lead, zinc, copper, and iron.

131. Lead is one of the most valuable materials for this purpose on account of its malleability and durability, the action of the atmosphere having no injurious effect upon it. Lead is used for covering roofs in sheets weighing from 4 to 8 lbs. per sup. foot.

132. Copper is used for covering roofs in thin sheets weighing about 16 oz. per sup. foot, and from its lightness and hardness has some advantages over lead; but the expense of the metal effectually precludes its general adoption.

133. Zinc has of late years superseded both lead and copper to a considerable extent as roof coverings. It is used in sheets weighing from 12 oz. to 20 oz. per sup. foot. It is considered an inferior material to those just named; but its lightness and cheapness are great recommendations, and the manufacture has been much improved since its first introduction.

134. Cast iron, coated with zinc to preserve it from rusting, is now much used in a variety of forms. We have already mentioned its adoption for covering the roofs of the New Houses of Parliament.

135. All metallic coverings are subject to contraction and expansion with the changes of the temperature, and great

care is requisite in joining the sheets to make them lap over each other, so as to make the joints water-tight, without preventing the play of the metal.

The following table of the comparative weights of different roof coverings may be useful :—

	Cwts.	qrs.	lbs.
Plain tiles, per square of 100 ft. sup. .	18	0	0
Pantiles	9	2	0
Slating, an average	7	0	0
Lead, 7 lb. to the sup. foot	6	2	0
Copper or zinc, 16 oz. do.	1	0	0

SUPPLY OF WATER.

136. The arrangements for distributing a supply of water over the different parts of a building will depend very materially on the nature of the supply, whether constant or intermittent.

The most common method of supply from water-works is by pipes which communicate with private cisterns, into which the water is turned at stated intervals.

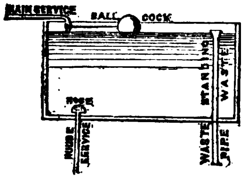
A cistern, in a dwelling-house, is always more or less an evil ; it takes up a great deal of space, costs a great deal of money in the first instance, and often causes inconvenience, from leakage, from the bursting of the service pipes in frosty weather, and from the liability of the self-acting cock to get out of order.

Fig. 68 shows the ordinary arrangements of a cistern for a dwelling-house. The common material for the cistern itself is wood lined with sheet lead ; but slate cisterns have been much used of late. Large cisterns or tanks for the supply of breweries, manufactories, &c., are usually made of cast-iron plates, screwed together by means of flanges all round their edges.

The service or feed pipe for a cistern, in the case of an

intermittent supply, must be sufficiently large to allow of its filling during the time the water is turned on from the mains. The flow of water into the cistern is regulated by a *ball cock*, so called from its being opened and shut by a lever, with a copper ball, which floats on the surface of the water.

Fig. 69.



The service pipes to the different parts of the building are laid into the bottom of the cistern, but should not come within an inch of the actual bottom, in order that the sediment, which is always deposited in a greater or less degree, may not be disturbed: the mouth of each pipe should be covered by a *rose*, to prevent any foreign substances being washed into the pipes and choking the taps.

To afford a ready means of cleaning out the cistern, a waste pipe is inserted quite at the bottom, sufficiently large to draw off the whole contents in a short time when required; into this waste pipe is fitted a *standing waste*, which reaches nearly to the top of the cistern, and carries off the waste water, when, from any derangement in the working of the ball cock, the water continues running after the cistern is full. To prevent any leakage at the bottom of the standing waste, the latter terminates in a brass plug, which is ground to fit a washer inserted at the top of the waste pipe.

Where the supply of water is *constant*, instead of being intermittent, private cisterns may be altogether dispensed with; the main service pipes, not being required to discharge a large quantity of water in a short time, may be of smaller bore, and, consequently, cheaper, and a considerable length of pipe is saved, as the water can be laid on directly to the several taps, instead of having to be taken up to the cistern and then brought back again. The constant flow of water through the pipes also much diminishes the risk of their bursting in frosty weather from freezing of their contents.

WARMING AND VENTILATION.

137. The various contrivances employed for warming buildings may be classed as under :—

Methods of Warming independently of Ventilation.

1st. By close stoves, the heating surface being either of iron or of earthenware.

2d. By hot-air flues, passing under the floors.

3d. By a system of endless piping heated by a current of hot water from a boiler, the circulation being caused by the cooling, and consequently greater weight, of the water in the lower or returning pipe.

Methods of Warming combined with Ventilation.

4th. By open fires placed in the several apartments.

5th. By causing air which has been previously heated to pass through the several rooms. This last system is more perfect than any of the others above described, both as regards economy of fuel and regulation of the temperature.

A great though common defect in the construction of fire-places is their being placed too high ; whence it is not unusual for the upper part of a room to be quite warm whilst there is a stratum of cold air next the floor, the effect of which is very injurious to health.

In all methods of warming, in which the air is heated by coming in contact with metallic heating surfaces, care should be taken that their temperature should not exceed 212° ; as, when this limit is exceeded, the air becomes unfit for use, and offensive from the scorching of the particles of dust or other matters that are always floating in it.

138. There are two modes in which artificial ventilation is effected, each of which is very efficient.

The one most in use is to establish a draught in an

shaft or chimney communicating by flues with the apartments to be ventilated, the effect of which is to cause a constant current in the direction of the shaft, the air being admitted at the bottom of the building, and warmed or cooled as may be required, according to the season of the year.

The new House of Lords is ventilated in this manner. The air is admitted at the bottom of the buildings, filtered by being passed through fine sieves, over which a stream of water is constantly flowing; warmed in cold weather by passing through steam cockles, and then, rising through the building, goes out through the roof into the furnace chimney, the draught being assisted by a steam jet from a boiler.

139. The other mode of ventilation to which we have alluded is on a completely opposite principle to that just described, the air being *forced into* the apartments by mechanical means, instead of being *drawn from* them by the draught in the chimney.

SECTION II.

MATERIALS USED IN BUILDING.

140. The materials used in building may be classed under the following heads, viz:

Timber, Stone, Slate, Bricks and Tiles, Limes and Cements, Metals, Glass, Colors and Varnishes.

TIMBER.

141. If we examine a transverse section of the stem of a tree, we perceive it to consist of three distinct parts: the *bark*, the *wood*, and the *pith*. The wood appears disposed in rings round the pith, the outer rings being softer and containing more sap than those immediately round the pith which form what is called the *heart wood*.

These rings are also traversed by rays extending from the centre of the stem to the bark, called *medullary rays*.

The whole structure of a tree consists of minute vessels and cells, the former conveying the sap through the wood in its ascent, and through the bark to the leaves in its descent; and the latter performing the functions of secretion and nutrition during the life of the tree. The solid parts of a tree consist almost entirely of the fibrous parts composing the sides of the vessels and cells.

By numerous experiments it has been ascertained that the sap begins to ascend in the spring of the year, through the minute vessels in the wood, and descends through the bark to the leaves, and, after passing through them, is deposited in an altered state between the bark and the last years's wood, forming a new layer of bark and sap wood, the old bark being pushed forward.

As the annual layers increase in number, the sapwood

ceases to perform its original functions ; the fluid parts are evaporated or absorbed by the new wood, and, the sides of the vessels being pressed together by the growth of the latter, the sap wood becomes heart wood or perfect wood, and until this change takes place it is unfit for the purposes of the builder.

The vessels in each layer of wood are largest on the side nearest the centre of the stem, and smallest at the outside. This arises from the first being formed in the spring, when vegetation is most active. The oblong cells which surround the vessels are filled with fluids in the early growth; but, as the tree increases in size, these become evaporated and absorbed, and the cells become partly filled with depositions of woody matter and indurated secretions, depending on the nature of the soil, and affecting the quality of the timber. Thus Honduras mahogany is full of black specks, while the Spanish is full of minute white particles, giving the wood the appearance of having been rubbed over with chalk. At a meeting of the Institution of Civil Engineers, March, 1842, it was stated by Professor Brande, that "a beech tree in Sir John Sebright's park in Hertfordshire, on being cut down, was found perfectly black all up the heart. On examination it was discovered that the tree had grown upon a mass of iron scoriæ from an ancient furnace, and that the wood had absorbed the salt of iron." This anecdote well explains the differences that exist between different specimens of the same kind of timber under different circumstances of growth ; and it is probably the nature of the soil that causes the difference of character we have just named between Honduras and Spanish mahogany.

There is a great difference in the character of the annual rings in different kinds of trees. In some they are very distinct, the side next the heart being porous, and the other being compact and hard, as the oak, the ash, and the elm. In others the distinctions between the rings is so small as scarcely to be distinguished, and the texture of the wood is

nearly uniform, as in the beech and mahogany. A third class of trees have the annual rings very distinct and their pores filled with resinous matter, one part being hard and heavy, the other soft and light-colored. All the resinous woods have this character, as larch, fir, pine, and cedar.

The medullary rings are scarcely perceptible to the naked eye in the majority of trees; but in some, as the oak and the beech, there are both large and small rings, which, when cut through obliquely, produced the beautiful flowered appearance called the silver grain.

142. In preparing timber for the uses of the builder there are three principal things to be attended to, viz., the age of the tree, the time of felling, and the seasoning for use.

143. If a tree be felled before it is of full age, whilst the heartwood is scarcely perfected, the timber will be of inferior quality, and, from the quantity of sap contained in it, will be very liable to decay. On the other hand, if the tree be allowed to stand until the heartwood begins to decay, the timber will be weak and brittle: the best timber comes from trees that have nearlv done growing, as there is then but little sapwood, and the heartwood is in the best condition.

144. The best time for felling trees is either in mid-winter, when the sap has ceased to flow, or in mid-summer, when the sap is temporarily expended in the production of leaves. An excellent plan is to bark the timber in the spring and fell it in winter, by which means the sapwood is dried up and hardened; but as the bark of most trees is valueless, the oak tree (whose bark is used in tanning) is almost the only one that will pay for being thus treated.

145. The seasoning of timber consists in the extraction or evaporation of the fluid parts, which are liable to decomposition on the cessation of the growth of the tree. This is usually effected by steeping the green timber in water, to dilute and wash out the sap as much as possible, and then

drying it thoroughly by exposure to the air in an airy situation. The time required to season timber thoroughly in this manner will of course much depend on the sizes of the pieces to be seasoned ; but for the general purposes of carpentry, two years is the least that can be allowed, and, in seasoning timber for the use of the joiner, a much longer time is usually required.

146. *Decay of Timber.*—Properly seasoned timber, placed in a dry situation with a free circulation of air round, it is very durable, and has been known to last for several hundred years without apparent deterioration. This is not, however, the case when exposed to moisture, which is always more or less prejudical to its durability.

When timber is constantly under water, the action of the water dissolves a portion of its substance, which is made apparent by its becoming covered with a coat of slime. If it be exposed to alternations of dryness and moisture, as in the case of piles in tidal waters, the dissolved parts being continually moved by evaporation and the action of the water, new surfaces are exposed, and the wood rapidly decays.

Where timber is exposed to heat and moisture, the albumen or gelatinous matter in the sapwood speedily putrefies and decomposes, causing what is called rot. The rot in timber is commonly divided into two kinds, the *wet* and the *dry*, but the chief difference between them is, that where the timber is exposed to the air, the gaseous products are freely evaporated ; whilst, in a confined situation, they combine in a new form, viz., the dry-rot fungus, which, deriving its nourishment from the decaying timber, often grows to a length of many feet, spreading in every direction, and insinuating its delicate fibres even through the joints of brick walls.

In addition to the sources of decay above mentioned, timber placed in sea-water is very liable to be completely destroyed by the perforations of the worm, unless protected by

copper sheathing, the expense of which causes it to be seldom used for this purpose.

147. *Prevention of Decay.*—The best method of protecting woodwork from decay when exposed to the weather is to paint it thoroughly, so as to prevent its being affected by moisture. It is, however, most important not to apply paint to any woodwork which has not been thoroughly seasoned; for in this case the evaporation of the sap being prevented, it decomposes, and the wood rapidly decays.

Many plans have been proposed for preventing the rot.

148. For a list of the varieties of timber for building purposes, see Appendix.

149. For internal finishings, mahogany is much used; that called Spanish, which comes from the West India Islands is considered the best.

For joiners' and cabinet makers' work, a great many kinds of fancy wood are imported, which are cut by machinery into thin slices, called *veneers*, and used as an ornamental covering to inferior work. In veneering care should be taken that the body of the work be thoroughly seasoned, or it will shrink, and the veneer fly off.

LIMES AND CEMENTS, MORTAR, ETC.

150. So much of the stability of brickwork and masonry depends upon the binding properties of the mortar or cement with which the materials are united, especially when exposed to a side pressure, as in the case of retaining walls, arches, and piers, that it is of no small importance to ascertain on what the strength of mortar really depends, and how far the proportions of the ingredients require modification, according to the quality of the lime that may have to be used.

It was long supposed that the hardness of any mortar depended upon the hardness of the limestone, from which the

lime used in its composition was derived; but it was ascertained by the celebrated Smeaton, and since his time clearly shown by the researches of others, amongst whom may be named, Vicat in France, and Colonel Pasley in England, that the hardness of the limestone has nothing to do with the matter, and that it is its chemical composition which regulates the quality of the mortar.

151. Limestone may be divided into three classes:

1st. Pure limes—as chalk.

2d. Water limes—some of which are only slightly hydraulic, as the stone limes of the lower chalk, whilst others are eminently so, as the lias limes.

3d Water cements—as those of Sheppy and Harwich.

152. In making mortar the following processes are gone through:

1st. The limestone is calcined by exposure to strong heat in a kiln, which drives off the carbonic acid gas contained in it, and reduces it to the state of *quick-lime.*

2d. The quick-lime is *slaked* by pouring water upon it, when it swells, more or less, with considerable heat, and falls into a fine powder, forming a *hydrate* of lime.

3d. The hydrate thus formed is mixed up into a stiffish paste, with the addition of more water, and a proper proportion of sand, and is then ready for use.

153. *Pure Limes.—Chalk* is a pure carbonate of lime, consisting of about 5 parts of lime combined with 4 of carbonic acid gas. It expands greatly in slaking, and will bear from three to 3½ parts of sand to one of lime, when made up into mortar. Chalk lime mortar is, however, of little value, as it *sets* or hardens very slowly, and in moist situations never sets at all, but remains in a pulpy state, which renders it quite unfit for any work subjected to the action of water, or even for the external walls of a building.

154. Gypsum, from which is made *plaster of Paris* for cornices and internal decorations, is granular sulphate of lime, and contains 26·5 of lime, 37·5 of sulphuric acid, and 17 of water. It slakes without swelling, with a moderate heat, setting hard in a very short time, and will even set under water; but as it is, like other pure limes, partly soluble in water, it is not suitable for anything but internal work.

155. *Water limes* have obtained their name from the property they possess, in a greater or less degree, of setting under water. They are composed of carbonate of lime, mixed with silica, alumina, oxide of iron, and sometimes other substances.

156. *Dorking lime*, obtained from the beds of the lower chalk, at Dorking, in Surrey; and *Halling lime*, from a similar situation near Rochester, in Kent, are the principal limes used in London for making mortar, and are slightly hydraulic; they expand considerably in slaking, but not so much as the pure limes, and will make excellent mortar when mixed with three parts of sand to one of lime. Mortar made with these limes sets hard and moderately quick, and *when set*, may be exposed to considerable moisture without injury; but they will not set under water, and are therefore unfit for hydraulic works, unless combined with some other substance, as *puzzolana*, to give them water-setting properties.

157. The *blue lias limes* are the strongest water limes in this country. They slake very slowly, swelling but little in the process, and set very rapidly even under water; a few days only sufficing to make mortar extremely hard. The lias limes will take a much smaller proportion of sand than the pure limes, the reason of which will be understood, when it is remembered that they contain a considerable proportion of silica and alumina, combined with the lime in their natural state, and consequently the proportion of sand which

makes good mortar with chalk lime, would ruin mortar made with lias limes.

In the Vale of Belvoir, where the lias lime is extensively used, the common practice is to use equal parts of lime and sand for inside, and half sand to one of lime for face work.

158. *Water Cements.*—These differ from the water limes, as regards their chemical composition, only in containing less carbonate of lime and more of silica and alumina. They require to be reduced to a fine powder after calcination, without which preparation they cannot be made to slake. The process of slaking is not accompanied by any increase of bulk, and they set under water in a short time, a few hours sufficing for a cement joint to become perfectly hard.

Cement will not bear much sand without its cementitious properties being greatly weakened, the usual proportion being equal parts of sand and cement.

159. The use of natural cement was introduced by Mr. Parker, who first discovered the properties of the cement-stone in the Isle of Sheppy, and took out a patent for the sale of it in 1796, under the name of Roman cement.

Before that time, hydraulic mortar, for dock walls, harbor work, &c., was usually made, by mixing common lime with trass, from Andernach in Germany, or with puzzolana from Italy; both are considered to be volcanic products, the latter containing silica and alumina, with a small quantity of lime, potash, and magnesia. Iron is also associated with it in a magnetic state.

160. The expense of natural puzzolana led to the manufacture of artificial puzzolana, which appears to have been used at an early date by the Romans, and has continued in use in the south of Europe to the present day; artificial puzzolana is made of pounded bricks or tile dust. The Dutch manufacture an artificial puzzolana from burnt clay,

in imitation of the trass of Andernach, which is said to be a close imitation of the natural product.

161. The great and increasing demand for cement, and its great superiority for most purposes over lime mortar, have induced manufacturers to turn their attention to the manufacture of artificial cement, and this has been attended in many instances with perfect success; the artificial cements now offered for sale, formed by imitating the composition of the natural cement-stones, being mostly equal in quality, if not superior, to the Roman cement, the use of which has been partly superseded by them.

162. The quality of the *sand* used in making mortar is by no means unimportant. It should be clean and sharp; *i. e.*, angular, and perfectly free from all impurities. The purer the lime the finer should be the quality of the sand, the pure limes requiring finer, and the cements a coarser sand, than the hydraulic limes.

CONCRETE AND BETON.

163. Rubble masonry, formed of small stones bedded in mortar, appears to have been commonly used in England from an early period; and similar work, cemented with hydraulic mortar, was constantly made use of by the Romans in their sea-works, of which many remains exist at the present day in a perfectly sound state.

164. This mode of forming foundations, in situations where solid masonry would be inapplicable, has been revived in modern times; in England and the United States under the name of concrete, and on the continent under the name of béton. Although very similar in their nature and use, there are yet great differences between béton and concrete, which depend on the nature of the lime used, concrete being made with the weak water limes which will not set under water, whilst béton is invariably made with water-setting limes, or

with limes rendered hydraulic by the addition of puzzolana. Describing the two by their differences, it may be observed that concrete is made with unslaked lime, and immediately thrown into the foundation pit; béton is allowed to stand before use, until the lime is thoroughly slaked; concrete is thrown into its place and rammed to consolidate it; béton is generally lowered and not afterwards disturbed; concrete must be thrown into a dry place, and not exposed to the action of water until thoroughly set; béton, on the contrary, is made use of principally *under water*, to save the trouble and expense of laying dry the bottom.

165. Concrete is usually made with gravel, sand, and ground unslaked lime, mixed together with water, the proportions of sand and lime being those which would make good mortar without the gravel, and, of course, varying according to the quality of the lime; with the common limes, slaking takes place at the time of mixing, and the quality of the concrete is all the better for the freshness of the lime. If lias lime be used, the concrete becomes béton, and must be treated accordingly.

The lime in this case must be thoroughly slaked (which often takes many hours) before it can be considered fit for use; and, if this precaution be not attended to, the whole of the work, after having set very hard on the surface, cracks and becomes a friable mass, from the slaking of the refactory particles after the body of the concrete has set.

166. Asphalte, so much in use at the present day for foot-pavements, terrace-roofs, &c., is made by melting the asphalte rock, which is a carbonate of lime intimately combined with bitumen, and adding to it a small portion of mineral tar, which forms a compact semi-elastic solid, admirably adapted for resisting the effects of frost, heat, and wet.

Many artificial asphaltes have been brought under public notice from time to time, but they are all inferior to the natural asphalte, in the intimate combination of the lime and

bitumen, which it appears impossible to effect thoroughly by artificial means.

METALS.

167. The metals used as building materials are iron, lead, copper, zinc, and tin.

168. *Iron.*—Iron is used by the builder in two different states, viz., cast iron and wrought iron, the differences between them depending on the proportion of carbon combined with the metal; cast iron containing the most, and wrought iron the least.

169. Previous to the middle of the last century, the smelting of iron was carried on with wood charcoal, and the ores used were chiefly from the secondary strata, although the clay ironstones of the coal measures were occasionally used.

170. The introduction of smelting with pitcoal coke during the last century caused a complete revolution in the iron trade. The ores now chiefly used are the clay ironstones of the coal measures, and the fuel, pitcoal, or coke. Steam power is almost exclusively used for the production of the blast in the furnaces, and for working the forge hammers and rolling mills.

171. For the production of wrought iron in the ordinary manner, two distinct sets of processes are required. 1st. The extraction of the metal from the ore in the shape of cast iron. 2nd. The conversion of cast iron into malleable or bar iron, by re-melting, puddling, and forging. The conversion of bar iron into steel is effected by placing it in contact with powdered charcoal in a furnace of cementation.

172. *Cast iron* is produced by smelting the previously calcined ore in a blast furnace, with a portion of limestone as a flux, and pitcoal or coke as fuel. The melted metal sinks to the bottom of the furnace by its greater specific gravity.

The limestone and other impurities float on the top of the melted mass, and are allowed to run off, forming *slag* or *cinder*. The melted metal is run off from the bottom of the furnace into moulds, where castings are required, and into furrows made in a level bed of sand, when the metal is required for conversion into malleable iron, the bars thus produced being called *pigs*.

173. In the year 1827, it was discovered that by the use of heated air for the blast, a great saving of fuel could be effected as compared with the cold blast process.

The hot blast is now very extensively in use, and has the double advantage of requiring less fuel to bring down an equal quantity of metal, and of enabling the manufacturer to use raw pitcoal instead of coke, so that a saving is effected both in the quantity and cost of the fuel.

For a considerable time after its introduction it was held in great disrepute, which, however, may be chiefly attributed to the inferior quality of materials used, the power of the hot blast in reducing the most refractory ores offering a great temptation to obtain a much larger product from the furnace than was compatible with the good quality of the metal. The use of the hot blast by firms of acknowledged character has greatly tended to remove the prejudice against it; and in many iron works of high character, nothing but the hot blast with pitcoal is used in the smelting furnaces, the use of coke being confined to the subsequent processes.

Perhaps it may be laid down as a general principle, that where the pig iron is re-melted with coke in the cupola furnace, for the purposes of the iron founder; or refined with coke in the conversion of forge pig into bar iron, it is of little consequence whether the reduction of the ore has been effected with the hot or the cold blast; but where castings have to be run directly from the smelting furnace, the quality of the metal will, no doubt, suffer from the use of the former.

174. Cast iron is divided by ironfounders into three qua-

lities. No. 1, or *black cast iron*, is coarse-grained, soft, and not very tenacious. When re-melted it passes into No. 2, or *grey cast iron*. This is the best quality for castings requiring strength : it is more finely grained than No. 1, and is harder and more tenacious. When repeatedly re-melted it becomes excessively hard and brittle, and passes into No. 3, or *white cast iron*, which is only used for the commonest castings, as sash-weights, cannon-balls, and similar articles. White cast iron, if produced direct from the ore, is an indication of derangement in the working of the furnace, and is unfit for the ordinary purposes of the founder, except to mix with other qualities.

175. Girders and similar solid articles are cast in sand moulds, enclosed in iron frames or *boxes*, each mould requiring an upper and lower box. A mould is formed by pressing sand firmly round a wooden *pattern*, which is afterwards removed, and the melted metal poured into the space thus left through apertures made for the purpose.

The moulds for ornamental work and for hollow castings are of a more complicated construction, which will be better understood from actual inspection at a foundry than from any written description.

Almost all irons are improved by admixture with others, and, therefore, where superior castings are required they should not be run direct from the smelting furnace, but the metal should be re-melted in a cupola furnace, which gives the opportunity of suiting the quality of the iron to its intended use. Thus, for delicate ornamental work, a soft and very fluid iron will be required, whilst, for girders and castings exposed to cross strains, the metal will require to be harder and more tenacious. For bedplates and castings which have merely to sustain a compressing force, the chief point to be attended to is the hardness of the metal.

Castings should be allowed to remain in the sand until cool, as the quality of the metal is greatly injured by the

rapid and irregular cooling which takes place from exposure to air if removed from moulds in a red hot state, which is sometimes done in small foundries to economise room.

The Scotch iron, which is so much esteemed for hollow wares, and has a beautifully smooth surface, is much used in the United States. The Scotch iron is softer, runs closer, and is used much for plates which require smoothness, for steam-engine cylinders, and work of like character, which requires *closeness*, or soundness; it is also mixed with our American iron. The Eastern iron is the best used in the United States for positions requiring great strength. The iron from the West is more like Scotch.

The Welch iron is principally used for conversion into bar iron.

176. The conversion of forge pig into bar iron is effected by a variety of processes, which have for their object the freeing the metal from the carbon and other impurities combined with it, so as to produce as nearly as possible the pure metal. We do not purpose to enter in these pages into any of the details of the manufacture of bar iron, or of its conversion into steel, as our business is rather with the iron-founder than the manufacturer ; it may, however, be proper to state that new processes have lately been patented, by which malleable iron and steel may be produced directly from the ore, without the use of the smelting furnace, a plan which is likely to be attended with beneficial results, both as regards economy and quality of metal.

177. *Lead.*—Lead is used by the mason for securing dowels, coating iron cramps, and similar purposes, *see* section IV., Plumber.

Lead is also used by the smith in fixing iron railings, and other work where iron is let into stone ; but the use of lead in contact with iron is always to be avoided, if possible, as it has an injurious effect upon the latter metal, the part in contact with the lead becoming gradually softened.

The chief value of lead, however, to the builder, is as a covering for roofs, and for lining gutters, cisterns, &c., for which uses it is superior to any other metal. For these purposes the lead is cast into sheets, and then passed between rollers in a *flatting-mill*, until it has been reduced to the required thickness.

Cast-lead is often made by plumbers themselves from old lead taken in exchange; but it is very inferior to the *milled lead* of the manufacturer, being not so compact, and often containing small air-holes, which render it unfit for any but inferior purposes.

178. *Copper.—See* Section IV., Coppersmith.

179. *Zinc.—See* Section IV., Zincworker.

180. *Brass* is an alloy of the copper and zinc, the best proportions being nearly two parts of copper to one of zinc.

181. *Bronze* is a compound of metal, composed of copper and tin, to which are sometimes added a little zinc and lead.

The best proportions for casting statues and bas-reliefs appear to be attained when the tin forms about 10 per cent. of the alloy.

By alloying copper with tin, a more fusible metal is obtained, and the alloy is much harder than pure copper; but considerable management is required to prevent the copper from becoming refined in the process of melting, a result which has frequently happened to inexperienced founders.

182. *Bell-metal* is composed of copper and tin, in the proportion of 78 per cent. of the former to 22 per cent. of the latter.

183. Cast iron lintels and columns are in common use in our cities. Cast iron blocks are also frequently used for the arches of bridges. Iron chains are used with advantage under the roofs of circular buildings.

STONE.

184. Granite rock appears to have been originally a fused mass, and subsequently to have undergone the process of crystallization. It is of a *granular* structure, that is, consisting of separate grains of different substances, united, apparently, without the aid of any intermediate matter or cement. These substances are *quartz*, *felspar*, and *mica*, each of these being a compound. The infinite variety of proportions in which their several constituent elements are united in the mass, occasions the great diversity of color, and of appearance of the several kinds of granite, and also affects in a much more important manner the enduring characteristics of this valuable material. Thus, its color varies from light grey to a dark tint closely resembling black, and is to be found of all shades of red, and many green. Of the constituents of granite, *quartz* is a substance of a glassy appearance, and of a grey color, and is composed of a metallic base *silicium* and *oxygen* : *felspar* is also a crystalline substance, but commonly opaque, of a yellowish or pink color, composed of silicious and aluminous mattter, with a small proportion of lime and potash ; *mica*, a glittering substance, principally consists of clay and flint, with a little magnesia and oxide of iron. Instead of the mica, another substance called *hornblende*, is found in some granites ; hornblende is a dark crystalline substance, composed of flint, alumina, and magnesia, besides a large poportion of the black oxide of iron. Granites in which hornblende exists are sometimes called Syenite, having first been found in the island of Syene in Egypt.

185. Granite is found in mountain-chains, and usually in rugged outlines, in nearly all parts of Europe and America. Although all granites are similar in structure, the difference in the proportions of its constituent substances occasions great difference in its enduring and useful properties. Some

varieties are exceedingly friable and liable to decomposition, while others, including that known as Sienite, suffer but imperceptibly from moisture and the atmosphere. The compact nature of a close-grained granite, having the felspar highly crystallized and free from stains or cracks, seems well calculated to resist the effect of air and water.

186. *Slate.*—The geologists recognised four kinds of slate, *mica slate*, *talcows slate*, *flinty slate*, and common or clay slate. Of these the last only is a material of extended use in the arts of building and construction. Clay slate, as its name implies, consists chiefly of clay in an indurated condition, and occasionally containing particles of mica and quartz, and in some of the coarser kinds, grains of felspar and other fragments of the primary rocks. In the extreme admixture of these foreign substances, clay slate approaches the nature of the rock known as grey wacke. The beds of clay slate are invariably stratified, the thickness of the strata, however, varying from a fraction of an inch to many feet. Its laminar texture admits a ready separation into thin plates, and thus endows it with a supreme value for roofing and other purposes, in which great density and comparative impermeability are required to coexist with a minimum thickness and weight. The weight of slates varies from 174 to 179 lbs. per cubic foot.

187. *Sandstones.*—These rocks, belonging, geologically, to various positions in the order of the strata of which the exterior of the earth is composed. Sandstones are principally silicious, and possess various degrees of induration. These stones weigh from 140 to 150 lbs. per cubic foot.

188. From the nature of the composition of sandstones, it results that their resistance against, or yielding to, the decomposing effects to which they are subjected, depends to a great extent, if not wholly, upon the nature of the cementing substance by which the grains are united; these latter

being comparatively indestructible. From the nature of their formation, sandstones are usually laminated, and more especially so when mica is present, the plates of which are generally arranged in planes parallel to their beds. Stones of this description should be carefully placed in constructions, so that these planes of lamination may be horizontal, for if placed vertically, the action of decomposition will occur in flakes, according to the thickness of the laminæ. Indeed, the best way of using all descriptions of stone is in the same position which they had in the quarry; but this becomes an imperative rule with those of laminated structure.

189. Uniformity of color is a tolerably correct criterion of uniformity of structure, and this constitutes, other circumstances being equal, one of the practical excellencies of building stones. The great injury occasioned to these materials by their absorption of moisture, leads properly to a preference for such stones as resist its introduction, for all above ground purposes. Those which imbibe and retain moisture are especially liable to disruption by frost, if exposed. The simplest method of finding out the disposition of stone to imbibe moisture is to immerse it for a lengthened period of time in water, and to compare the weight of it before and after such immersion.

190. *Limestones.*—The class of limestones, including the magnesian limestones and the oolites, is one of extreme importance in the building arts, comprehending some of the most advantageous materials of construction, and combining great comparative durability with peculiar facilities for working, in which they surpass the sandstones. Of the limestones and the oolites, the principal material is carbonate of lime. The magnesian limestones contain a quantity of carbonate of magnesia, in some cases nearly equal to that of carbonate of lime.

191. It is remarked that magnesian limestone appears capable of resisting decomposing action in proportion as its structure is crystalline.

SLATE.

192. *See* Section IV.

GLASS.

193. *See* Section IV.

BRICKS AND TILES.

194. According to the Bible, burnt bricks were used in the Tower of Babel.

In Egypt, bricks were made of clay, mixed with dried straw, and dried in the sun.

195. The usual form of a brick is a paralellopipedon, about 9 in. long, 4½ in. broad, and 2¼ to 3 in. thick—the exact size varying with the construction of the clay. The thickness need not bear any definite proportion to the length and breadth, but these last dimensions require nice adjustment, as the length should exceed twice the breadth by the thickness of a mortar joint.

196. The manufacture of tiles is similar to that of bricks, the principal difference arising from the thinness of the ware.

Paving tiles may be considered simply a thin brick.

Roofing tiles are of two kinds: pantiles, which are of a curved shape, and plaintiles, which are flat, the latter being often made of ornamental shapes so as to form elegant patterns when laid on a roof.

Pantiles are moulded flat, and afterwards bent into their required shape on the mould. Plaintiles were formerly made with holes in them for the reception of the tile-pins, by which they were hung on the laths; but the common method now is to turn down a couple of nibs at the head of the tile, which answer the same purpose.

197. *Draining tiles* are the coarsest kind of earthenware. They are of various shapes, and are made in various ways.

198. Glass. *See* Section IV.

199. Colors and varnishes. *See* Section IV.

SECTION III.

STRENGTH OF MATERIALS.

200. There are three principal actions to which the materials of a building are exposed.

1st. *Compression*—as the case of the stones in a wall.

2nd. *Tension*—as in the case of a king-post or tie-beam.

3rd. *Cross-strain*—as in the case of a bressummer, floor-joists, &c.

The last of the three is the only one against which precautions are especially necessary, as in all ordinary cases the resistance of the materials used for building is far beyond any direct crushing or pulling force that is likely to be brought upon them.

201. 1st. *Resistance to Compression.*—The following table shows the force required to crush 1½ in, cubes of several kinds of building material:—

	lbs.		lbs.
Good brick . .	1817	Portland stone . .	10,284
Derbyshire grit .	7070	Granite " . . .	14,300.

These amounts so far exceed any weight that could have to be borne on an equal area, under ordinary circumstances, that it is quite unnecessary in the erection of a building to make any calculations on this head when using these or similar materials.

Cast iron may be considered as practically incompressible; *wrought iron* may be flattened under great pressure, but cannot be crushed. *Timber* may be considered, for practical purposes, as nearly incompressible, when the weight is applied in the direction of the fibres, as in the case of a wooden story-post; but the softer kinds, as fir, offer little resistance,

when the weight is applied at right angles to the fibres, as in the case of the sill of a partition; and, beside this, timber, however well-seasoned, will always shrink, more or less, in the direction of its thickness, so that no important bearings should be trusted to it.

202. 2nd. *Resistance to Tension.*—The principal building materials that are required to resist direct tension are *timber* and *wrought iron.*

The following table shows the weight in tons required to tear asunder bars 1 inch square of the following materials:—

	Tons.
Oak	5 1-6
Fir	5¼
Cast iron	7¾
Wrought iron	10
Wrought copper	15
English bar iron	25
American iron	37½
Blistered steel	59½

Cast iron, however, although included in the above table, is an unsuitable material for the purpose of resisting tension, being comparatively brittle. With regard to *timber*, it is practicably impossible to tear asunder a piece of even moderate size, by a force applied in the direction of the fibres, and therefore the dimensions of king-posts, tie-beams, and other timbers which have to resist a pulling force, are regulated by the necessity of forming proper joints and connections with the other parts of the framing to which they belong, rather than by their cohesive strength. But it must be borne in mind, that although the strength of all kinds of timber is very great in the direction of the fibres, the lateral cohesion of the annual rings is in many kinds of wood very slight, and must be assisted by iron straps in all doubtful cases. The architects of the middle ages executed their magnificent wooden roofs without these aids, but they worked

in oak, and not in soft fir, which would split and rend if treated in the same way.

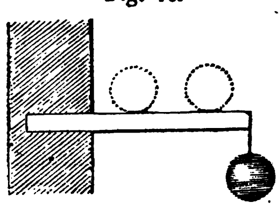
Wrought iron is extensively used for bolts, straps, tie-rods, and all purposes which require great strength, with small sectional area; one-fourth of the breaking weight is usually said to be the limit to which it should be strained; but, in all probability, this amount might be doubled without any injurious effects.

STRENGTH OF BEAMS.

203. 3rd. *Cross Strain.*—In calculating the strength of beams when exposed to cross or transverse strain, two principal considerations present themselves: 1st. The mechanical effect which any given load will produce under varying conditions of support: and 2ndly. The resistance of the beam, and the manner in which this is affected by the form of its section.

204. 1st. *Mechanical Effect of a given Load under varying Circumstances.*—If a rectangular beam be supported at each end and loaded in the middle, the strength of the beam, its section remaining the same, will be inversely as the distance between the supports, the weight acting with a leverage which increases at this distance.* If a beam be fixed at one

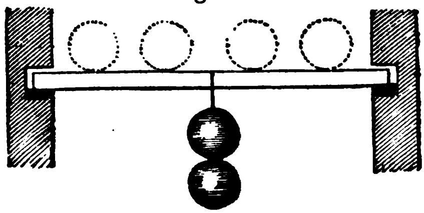
Fig. 70.



* It may be as well to observe that, although this is true as to the strength of beams under ordinary circumstances, it does not hold good when the loading is carried to the breaking point, the deflection of the beam causing an increase or diminution of the leverage according to the mode of support. The difference of strength arising from this cause is, however, too trifling to be taken into consideration, except in delicate experiments on the ultimate strength of beams.

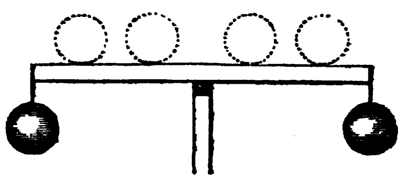
end and weighted at the other (fig. 70), its strength will be half that of a similar beam of double the length supported as first described (fig. 71). A parallel case to this is that of a beam supported in the middle and loaded at the ends

Fig. 71.



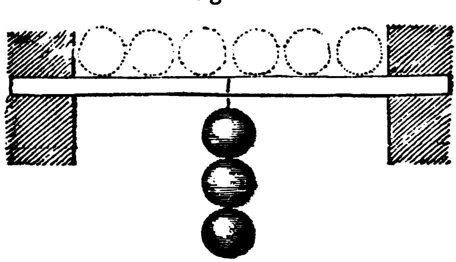
(fig. 72). In each of the above cases the beam will bear double the load if it be equally distributed over its whole

Fig. 72.



length, as shown by the dotted lines; and lastly, the strength of a beam firmly fixed at the ends is to its strength when loosely laid on supports as 3 to 2 (*see* fig. 73).

Fig. 73.



These results may be simply expressed thus:

Let *s* be the weight which would break a beam of given length and scantling fixed at one end and loaded at the other:

then 2 *s* would break the same beam fixed at one end and uniformly loaded:

4 *s* would break the same beam supported at each end and loaded in the middle:

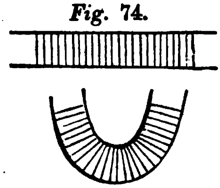
6 *s* would break the same beam fixed at each end and loaded in the middle:

8 *s* would break the same beam supported at each end and uniformly loaded:

12 *s* would break the same beam fixed at each end and uniformly loaded.

205. 2d. *Resistance of the Beam.*—If a beam be loaded so as to produce fracture, this will take place about a centre or neutral axis, below which the fibres will be *torn* asunder, and above which they will be *crushed.* This may be very clearly illustrated by drawing a number of parallel lines with a soft pencil on the edge of a piece of India rubber, and bending it round, when it will be seen that the lines are brought closer together on the concave, and stretched further asunder on the convex side, whilst, between the two edges, a neutral line may be traced, on which the divisions remain of the original size, which neutral line divides the fibres that are subjected to compression from those in a state of tension (*see* fig. 74).

Fig. 74.



The resistance of a rectangular beam will, therefore, depend, 1st, on the number of fibres, which will be proportionate to its breadth and depth; 2d, on the distance of those fibres from the neutral axis, and the consequent leverage with which they act, which will also be as the depth; and, lastly, on the actual strength of the fibres, which will

vary with different materials, and can only be determined approximately from actual experiments on rectangular beams of the same material as those whose strength is required to be estimated.

The actual strength of any rectangular beam will, therefore, be directly as its breadth multiplied by the square of the depth, and inversely as its length; or, calling s the transverse strength of the material, as in art. 177, b the breadth, d the depth, l the length between the supports, and W the breaking weight:

$$W = \frac{s\,b\,d^2}{l}.$$

The following may be taken as the value of s for iron and timber, the length being taken in feet, the breadth and depth in inches, and the breaking weight in pounds.

	Constant multiplier for rectangular beams fixed at one end and loaded at the other.		Constant multiplier for rectangular beams loosely supported at the ends and loaded in the middle.
Wrought iron	512	× 4	2048
Cast ditto	500		2000*
Fir and English oak			400

It must be remembered that the numbers here given indicate the breaking weight, not more than one-third of which should ever be applied in practice. Timber is permanently injured if more than even one-fourth of the breaking weight is placed on it, and, therefore, this limit should never be passed.

A single example will suffice to show the importance of the principles just explained, and the lamentable results that may follow from ignorance of them. If we take a fir binding-joist, say 9 in. × 4 in., which is to have a bearing of 12 ft. between its supports, and place it edgeways, it will require to break it a weight $= \frac{400 \times 4 \times 9^2}{12} = 10{,}800$ lbs.;

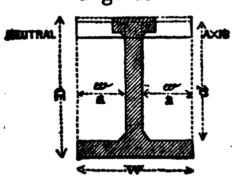
* The above is an average value calculated from a great number of published experiments on different irons.

but if, for the purpose of gaining height, we place it flat-ways, it will break with a weight $= \frac{400 + 9 + 4^2}{12} = 4{,}800$ lbs.; or less than one-half.

206. We may see from this example that the shape of any beam has a great influence on its strength; and in making beams of iron, which can be cast with great facility in any required shape, it becomes an important question how to obtain the strongest form of section with the least expenditure of metal.

The usual section given to cast-iron girders is that of a thin and deep rectangular beam, with flanges or projections on each side at top and bottom; where the strength of the metal will be most effective, as being at the greatest possible distance from the neutral axis (fig. 78).

Fig. 78.



The great question now is, what should be the relative thickness of the top and bottom flanges, the centre part of the beam having been made as thin as is consistent with sound casting?

If the metal were incompressible, the top flanges might be infinitely thin; if incapable of extension, the bottom ones might be indefinitely reduced. If it offered equal resistance to tension and compression, the neutral axis would occupy the centre of the beam, and the top and bottom flanges would require to be of equal strength.

We are indebted to Mr. Eaton Hodgkinson for the publication* of a valuable set of experiments conducted by him, having for their object the determination of the position of the neutral axis in cast-iron beams. The result of his

* Experimental Researches on the Strength and other Properties of Cast Iron, 8vo, 1846. WEALE.

experiments is, that in cast-iron rectangular beams, the position of the neutral axis at the time of fracture is at about one-seventh of the whole depth of the beam below its upper surface. Hence, in girders with flanges, the thickness of the bottom flanges should be six times that of the upper ones (supposing them to be of the same width), in order to obtain the greatest strength with the least metal. Practically it would be almost impossible to cast a beam thus proportioned, and, therefore, the top flanges are made of the same thickness, or nearly so, as the bottom ones, but of a less width, so as to contain the same relative quantity of metal, disposed in a more convenient form for casting (fig. 75).

The difficulty of making sound castings where the parts are of unequal thickness also renders it necessary to make the thickness of the middle rib nearly equal to that of the flanges.

207. To calculate the strength of a cast-iron beam, the sectional area of whose top flanges is 1-6 of that of the bottom ones, we must find that of a rectangular beam of the same extreme depth and width, and deduct from it the resistance of the portions omitted between the top and bottom flanges (fig. 75).

If we call the whole width of the bottom of the beam, W, the sum of the widths of the two bottom flanges, w, the whole depth of the beam, D, and the vertical distance between the flanges, d (on the supposition that the top flanges are of the same widths as the bottom ones, and 1-6 of their thickness, as shown by the dotted lines in fig. 78), the distance between the supports, l, the strength of the material, s, and if the weight required to break a beam when loosely supported at the ends and loaded in the middle be called x,

$$\text{Then } x = \frac{(W\,D^2 - w\,d^2)\,4\,s}{l},$$

and if we take the length in feet and the other dimensions

in inches, and call $s = 560$ lbs., which is not too much for the best Staffordshire irons; then

$4\,s = 2{,}240$ lbs. $= 1$ ton; and therefore $\dfrac{W\,D^2 - w\,d^2}{s} =$ breaking weight in tons.

The value of d in this rule will be D — 7-6 of the thickness of the bottom flanges, and so long as the sectional area of the top flanges is more than 1-6 of that of the bottom ones*, the rule may be applied to girders of variously proportioned flanges, as the additional strength gained by increasing the size of the top flanges beyond the proportion here named is very small in proportion to the metal used, and, in neglecting to take it into account, we are sure to err on the safe side.

208. It must not be supposed, that because increasing the thickness of the top flanges does not materially increase the resistance to vertical pressure, it is on that account useless: on the contrary, where a beam is of considerable depth in proportion to the widths of the bottom flanges, it will often be desirable to make the top flanges more than 1-6 of the bottom ones, in order to prevent the girder from twisting laterally, and to increase the resistance to any side thrust to which it may be exposed from brick arches or otherwise.

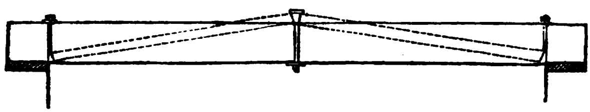
209. In practice, it is not desirable to load iron girders beyond ⅙ of their ultimate strength, and they should be *proved* before use by loading them to this extent or a little more, but care should be taken never to let the proof exceed ⅓ the breaking weight, as a greater load than this strains and distresses the metal, making it permanently weaker. The ultimate strength of a girder of the usual proportions may be approximately ascertained from its deflexion under proof

* It must be remembered that in making the top flanges narrower than the bottom ones for convenience of casting, as the bulk of the metal is brought nearer to the neutral axis by so doing, the sectional area of the top flanges must be rather more than 1-6 of that of the bottom ones, in order to keep the position of the neutral axis the same as in a rectangular beam.

on the assumption that a load equal to half the breaking weight will cause a deflection of 1-480th of its length.

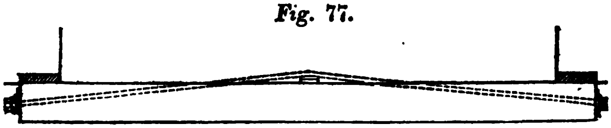
210. *Trussed Timber Beams.*—Timbers exposed to severe strain require to be *trussed* with iron, and this may be done in two ways: 1*st*, by inserting cast-iron struts, as in fig. 76, thus placing the whole, or nearly the whole, of the wood-

Fig. 76.



work in a state of tension; 2d, by wrought-iron tension rods, as in fig. 77, which take the whole of the tension,

Fig. 77.



whilst the timber is thrown entirely into compression. The latter mode of trussing is now very extensively used in strengthening the carriages of traveling cranes and for similar purposes; and, by its use, a balk of timber which will barely support its own weight safely without assistance, may be made to carry a load of many tons without sensible deflection.

STRENGTH OF STORY-POSTS AND CAST-IRON PILLARS.

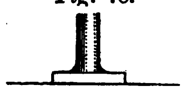
211. When a piece of timber, whose length is not less than 8 or 10 times its diameter, is compressed in the direction of its length, as in the case of a wooden story-post supporting a bressummer, it will give way if loaded beyond a certain point, not by crushing, but by bending, and will ultimately be destroyed by the cross-strain, just as a horizontal beam would be by vertical pressure applied at right angles to the

fibres. The rules for determining the dimensions of a piece of timber to support a given weight without sensible flexure are very complicated, and are of little practical value, as they depend upon the condition that the pressure is exactly in the direction of the axis of the post—a condition rarely fulfilled in practice.

212. Wooden story-posts have been to a great extent superseded by the use of cast-iron pillars, which possess great strength with a small sectional area, and are on that account particularly well adapted to situations where it is of consequence to avoid obstructing light, as in shop-fronts.

In determining the design of a cast-iron pillar, whose length is 20 or 30 times its diameter, two points have to be considered: 1st, the liability to flexure; 2d, the risk of the ends being crushed by the load not acting in the direction of the axis of the pillar.

Fig. 78.



The resistance to flexure is greatly increased by enlarging the bearing surface at the ends of the pillar, as in fig. 78, which, on the other hand, increases the liability of the ends to fracture, in the event of the load being thrown on the side instead of on the centre of the column, by any irregular settlement of the building. The judicious architect will, therefore take a mean course, swelling out the capitals and bases of his cast-iron pillars enough to prevent their shafts from bending, but at the same time avoiding any thin flanges or projections, which might be liable to be broken. No theoretical rule for determining the proportions of a cast-iron pillar depending on the weight to be supported can be depended on in practice. The real measure of the strength of a cast-iron story post must be the power of resisting any lateral force which may be brought against it; and as a slight side blow will suffice to fracture a pillar which is capable of supporting a vertical pressure of very many tons, we have only to make

sure of the lateral strength, and we are quite certain to be on the safe side as regards any vertical pressure which it may have to sustain.

213. Besides the above cases of transverse strain, there are others arising from irregular settlements, which are amongst the greatest difficulties with which the builder has to contend. Thus, to take a familiar instance, the window sills of a dwelling-house are often broken by the settlement of the brick-work being greater in the piers than under the sills, from the greater pressure on the mortar joints; and this will take place with a difference of settlement which can scarcely be detected, even by careful measurement*. We need not here enlarge on this subject, as we have several times in the preceding pages had occasion to notice both the causes of irregular settlement, and the precautions to be taken for its prevention.

The strength of materials to resist *torsion* or twisting, as in the case of a driving shaft, is an important consideration in the construction of machinery, but is of little consequence in the erection of buildings, and therefore need not be noticed in these pages.

* The reader need scarcely be told that a careful builder will always defer *pinning up* his sills until some time has been allowed for the settlement of the brick-work, but this will not always prevent ultimate fracture.

SECTION IV.

USE OF MATERIALS.

EXCAVATOR.

214. The digging required for the foundations of common buildings usually forms part of the business of the bricklayer, and is paid for at per cubic yard, according to the depth of the excavation, and the distance to which the earth has to be wheeled; this being estimated by the *run* of 20 yards.

In large works, which require coffer-dams and pumping apparatus to be put down before the ground can be got out for the foundations, the work assumes a different character, and is paid for accordingly; the actual excavation being only a small item of the total cost compared with those of dredging, piling, puddling, shoring, pumping, &c.

The workmen required for the construction of coffer-dams and similar works are laborers of a superior class, accustomed to the management of pile-engines and tackle, and competent to the execution of such rough carpenter's work as is required in timbering large excavations.

BRICKLAYER.

215. The business of a bricklayer consists in the execution of all kinds of work in which brick is the principal material; and in London it always includes tiling and paving with bricks or tiles. Where undressed stone is much used as a building material, the bricklayer executes this kind of work also, and in the country, the business of the plasterer is often united with the above named branches.

216. The tools of the bricklayer are the *trowel*, to take up and spread the mortar, and to cut bricks to the requiste length: the *brick axe*, for shaping bricks to any required bevel; the *tin saw*, for making incisions in bricks to be cut with the axe, and a *rubbing-stone*, on which to rub the bricks smooth after being roughly axed into shape. The *jointer* and the *jointing-rule* are used for *running* the centres of the mortar-joints. The *raker*, for raking out the mortar from the joints of old brick-work previous to re-pointing. The *hammer*, for cutting chases and splays. The *banker* is a piece of timber about 6 feet long, raised on supports to a convenient height to form a table on which to cut the bricks to any required gauge, for which *moulds* and *bevels* are required. The *crowbar*, *pick-axe*, and *shovel* are used in digging out the foundations, and the *rammer* in punning the ground round the footings, and in rendering the foundation firm where it is soft by beating or ramming.

To set out the work and to keep it true, the bricklayer uses the *square*, the *level*, and the *plumb-rule*; for circular or battering work he uses *templets* and *battering-rules*; *lines* and *pins* are used to lay the courses by; and *measuring-rods* to take dimensions. When brick-work has to be carried up in conjunction with stone-work, the height of each course must be marked on a *gauge-rod*, that the joints of each may coincide.

217. The bricklayer is supplied with bricks and mortar by a laborer, who carries them in a *hod*. The laborer also makes the mortar, and builds and strikes the scaffolding.

218. The bricklayer's scaffold is constructed with *standards*, *ledgers*, and *putlogs*. The standards are fir poles, from 40 to 50 ft. long, and 6 or 7 in. diameter at the butt ends, which are fimly bedded in the ground. When one pole is not sufficently long, two are lashed together, top and butt, the lashings being tightened with wedges. The ledgers are horizontal poles placed parallel to the walls, and lashed to

the standards for the support of the putlogs. The putlogs are cross pieces, usually made of birch, and about 6 ft. long, one end resting in the wall, the other on a ledger. On the putlogs are placed the scaffold boards, which are stout boards hooped at the ends to prevent them from splitting.

A bricklayer and his laborer will lay in a single day about 1000 bricks, or about two cubic yards.

The tools required for tiling are—the *lathing-hammer*, with two gauge marks on it, one at 7, and the other at 7½ inches; the *iron lathing staff*, to clinch the nails; the *trowel*, which is longer and narrower than that used for brick-work; the *bosse*, for holding mortar and tiles, with an iron hook to hang it to the laths or to a ladder; and the *striker*, a piece of lath about 10 in. long, for clearing off the superfluous mortar at the feet of the tiles.

219. Brick-work is measured and valued by the rod, or by the cubic yard, the price including the erection and use of scaffolding, but not centering to arches, which is an extra charge.

Bricknogging, pavings, and facings, by the superficial yard.

Digging and steining of wells and cesspools by the foot in depth, according to size, the price increasing with the depth.

Plain tiling and pantiling are valued per square of 100 feet superficial.

MASON.

220. The business of the mason consists in *working* the stones to be used in a building to their required shape, and in *setting* them in their places in the work. Connected with the trade of the mason are those of the *Stonecutter*, who *hews* and cuts large stones roughly into shape preparatory to their being *worked* by the mason, and of the *Carver*, who executes the ornamental portions of the stone-work of a building, as enriched cornices, capitals, &c.

221. Where the value of stone is considerable, it is sent from the quarry to the building in large blocks, and cut into slabs and scantlings of the required size with a stone-mason's saw, which differs from that used in any other trade in having no teeth. It is a long thin plate of steel, slightly jagged on the bottom edge, and fixed in a frame; and, being drawn backwards and forwards in a horizontal position, cuts the stone by its own weight. To facilitate the operation, a heap of sharp sand is placed on an inclined plane over the stone, and water allowed to trickle through it, so as to wash the sand into the saw-cut. Of late years machinery worked by steam-power has been used for sawing marble into slabs to a very great extent, and has almost entirely superseded manual labor in this part of the manufacture of chimney-pieces.

Some freestones are so soft as to be easily cut with a toothed saw worked backwards and forwards by two persons.

The harder kinds of stones, as granites and gritstones, are brought roughly into shape at the quarry, with an axe or a scappling hammer, and are then said to be *scappled.*

222. The tools used by the mason for cutting stone consist of the *mallet* and *chisels* of various sizes. The mason's mallet differs from that used by any other artisan, being similar to a dome in contour, excepting a portion of the broadest part, which is rather cylindrical; the handle is short, being only sufficiently long to enable it to be firmly grasped.

In London the tools used to work the faces of stone are the *point*, which is the smallest description of chisel, being never more than a quarter of an inch broad on the cutting edge; the *inch tool;* the *boaster*, which is 2 in. wide; and the *broad tool*, of which the cutting edge is 3½ in. wide. The tools used in working mouldings and in carving are of various sizes, according to the nature of the work.

Besides the above cutting tools the mason uses the

banker or bench, on which he places his stone for convenience of working, and *straight edges, squares, bevels*, and *templets*, for marking the shapes of the blocks, and for trying the surfaces as the work proceeds. Any angle greater or less than a right angle is called a bevel angle, and a *bevel* is formed by nailing two straight edges together at the required angle; a *bevel square* is a square with a shifting stock which can be set to any required bevel. A templet is a pattern for cutting a block to any particular shape; when the work is moulded, the templet is called a *mould*. Moulds are commonly made of sheet zinc, carefully cut to the profile of the mouldings with shears and files.

For setting his work in place the mason uses the *trowel, lines, and pins*, the *square* and *level*, and *plumb*, and *battering rules*, for adjusting the faces of upright and battering walls.

223. The mason's scaffold is double, that is, formed with two rows of standards, so as to be totally independent of the walls for support, as putlog holes are inadmissible in masonry.

During the last ten years the construction of scaffolds with round poles lashed with cords has been entirely superseded in large works by a system of scaffolding of square timbers connected by bolts and dog irons.

The hoisting of the materials is performed from these scaffolds by means of a traveling crane, which consists of a double traveling carriage running on a tramway formed on stout sills laid on the top of two parallel rows of standards. The crab-winch is placed on the upper carriage, and, by means of the double motion of the two carriages, can be brought with great ease and precision over any part of the work lying between the two rows of standards.

The facilities which are afforded by these scaffolds and traveling cranes for moving heavy weights over large areas, have led to their extensive adoption, not only in the erection of buildings, but on landing wharfs, masons and ironfound-

ers' yards, and similar situations, where a great saving of time and labor is effected by their use.

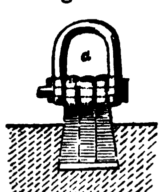
224. The movable derrick crane is also much used in setting mason's work. It consists of a vertical post supported by two timber backstays, and a long movable jib or derrick hinged against the post below the gearing.

By means of a chain passed from a barrel over a pully at the top of the post, the derrick can be raised almost to a vertical, or lowered to an almost horizontal position, thus enabling it to command every part of the area of a circle of a radius nearly equal to the length of the derrick. This gives it a great advantage over the old gibbet crane, which only commands a circle of a fixed radius, and the use of which entails great loss of time from its constantly requiring to be shifted as the work proceeds.

225. In hoisting blocks of stone they are attached to the tackle by means of a simple contrivance called a *lewis*, which is shown in fig. 79.

A tapering hole having been cut in the upper surface of the stone to be raised, the two side pieces of the lewis are inserted and placed against the sides of the hole; the centre parallel piece *a* is then inserted and secured in its place by a pin passng through all three pieces, and the stone may then be safely hoisted, as it is impossible for the lewis to draw out of the hole. By means of the lewis, in a slightly altered form from that here shown, stones can be lowered and set under water without difficulty, the lewis being disengaged by means of a line attached to the parallel piece; the removal of which allows the others to be drawn out of the mortice.

Fig. 79.

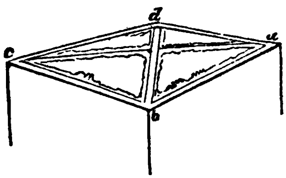


226. In stone-cutting, the workman forms as many plane faces as may be necessary for bringing the stone into the

required shape, with the least waste of material and labor, and on the plane surfaces so formed applies the moulds to which the stone is to be worked

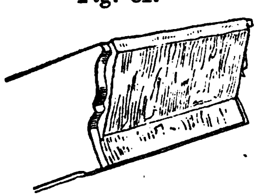
To form a plane surface, the mason first knocks off the superfluous stone along one edge of the block, as *a, b* (fig. 80), until it coincides with a straight edge throughout its whole length ; this is called a *chisel draught.* Another chisel draught is then made along one of the adjacent edges as *b, c,* and the ends of the two are connected by another draught, as *a c;* a fourth draught is then sunk across the last, as *b, d,* which gives another angle point *d,* in the same plane with *a b,* and *c,* by which the draughts *d a* and *a c* can be formed ; and the stone is then knocked off between the outside draughts until a straight edge coincides with the surface in every part.

Fig. 80.



To form cylindrical or moulded surfaces curved in one direction only, the workman sinks two parallel draughts at the opposite end of the stone to be worked, until they coincide with a mould cut to the required shape, and afterwards works off the stone between these draughts, by a straight edge applied at right angles to them (fig. 81).

Fig. 81.



The formation of conical or spherical surfaces is much less simple, and require a knowledge of the scientific operations of stone-cutting, a description of which would be unsuited to the elemetary character of these pages.

227. The finely-grained stones are usually brought to a smooth face, and rubbed with sand to produce a perfectly even surface.

In working soft stones, the surface is brought to a smooth face with the *drag*, which is a plate of steel, indented on the edge like the teeth of a saw, to take off the marks of the tools employed in shaping it.

The harder and more coarsely grained stones are generally *tooled*, that is, the marks of the chisel are left on their face. If the furrows left by the chisel are disposed in regular order, the work is said to be *fair-tooled*, but if otherwise, it may be *random-tooled* or *chiseled* or *boasted* or *pointed*. If the stones project beyond the joints, the work is said to be *rusticated*.

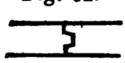
Granite and gritstone are chiefly worked with the scappling hammer. In massive erections, where the stones are large, and a bold effect is required, the fronts of the blocks are left quite rough, as they come out of the quarry, and the work is then said to be *quarry pitched*.

Many technical terms are used by quarrymen and others engaged in working stone ; but they need not be inserted here, as they are mostly confined to particular localities beyond which they are little known, or perhaps bear a different signification.

228. When the mason requires to give to the joints of his work greater security than is afforded by the weight of the stone and the adhesion of the mortar, he makes use of *joggles*, *dowels*, and *cramps*.

Stones are said to be joggled together when a projection is worked out on one stone to fit into a corresponding hole or groove in the other (*see* fig. 82). But this occasions great labor and waste of stone, and *dowel-joggles* are chiefly made use of, which are hard pieces of stone, cut to the required size, and let into corresponding mortices in the two stones to be joined together.

Fig. 82.



Dowels are pins of wood or metal used to secure the joints of stone-work in exposed situations, as copings, pin-

nacles, &c. The best material is copper; but the expense of this metal causes it to be seldom used. If iron be made use of, it should be thoroughly thinned to prevent oxidation, or it will, sooner or later, burst and split the work it is intended to protect.

Dowels are often secured in their places with lead poured in from above, through a small channel cut in the side of the joint for that purpose; but a good workman will eschew lead, which too often finds his way into bad work, and will prefer trusting to very close and workmanlike joints, carefully fitted dowels, and fine mortar; dowels should be made tapering at one end, which ensures a better fit, and renders the setting of the stone more easy for the workman.

Iron cramps are used as fastenings on the tops of copings, and in similar situations; but they are not to be recommended, as they are very unsightly, and, if they once become exposed to the action of the atmosphere, are powerfully destructive agents. Cast iron is, however, less objectionable than wrought iron for this purpose.

229 In measuring mason's work, the cubic content of the stone is taken as it comes to the *banker*, without deduction for subsequent waste.

If the scantlings are large, an extra price is allowed for hoisting.

The labor in working the stone is charged by the superficial foot, according to the kind of work, as plain work, sunk work, moulded work, &c

Pavings landings, &c., and all stones less than three in. thick, are charged by the superficial foot.

Copings, curbs, window sills, &c., are charged per lineal foot.

Cramps, dowels, mortice holes, &c., are always charged separately.

The remuneration of a stone-carver is dependent on his talent, and the kind of work he is engaged upon.

CARPENTER.

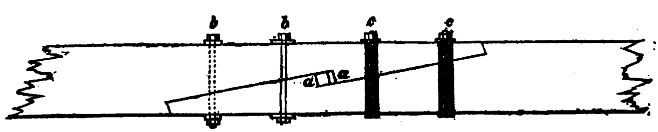
230. The business of the carpenter consists in framing timbers together, for the construction of roofs, partitions, floors, &c.

231. The capenter's principal tools are the axe, the adze, the saw, and the chisel, to which may be added the chalk, line, plumb-rule, level, and square. The work of the carpenter does not require the use of the plane, which is one of the principal tools of the joiner, and this forms the principal distinction between these trades, the carpenter being engaged in the rough frame-work, and the joiner on the finishings and decorations of buildings.

232. The principles of framing have been already fully described in the 1st section of this work, and we shall, therefore, confine our remarks on the operations of the carpenter to a description of the principal joints made use of in framing.

Timbers that have to be joined in the direction of their length, are *scarfed*, as shown in fig. 83; the double wedges. *a a*, serve to bring the timbers *home*, when they are secured,

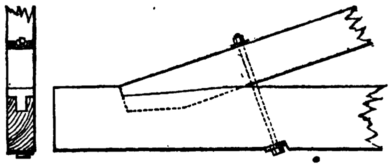
Fig. 83.



either by bolts, as shown at *b b* or by straps, as at *c c*, the latter being the most perfect and the most expensive fastening.

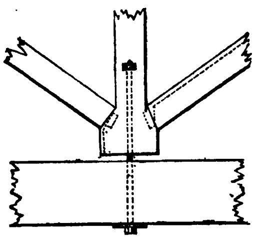
Fig. 84 shows the manner of connecting the foot of a principal rafter with a tie-beam. The bolt here shown keeps

Fig. 84.



the rafter in its place, and prevents it from slipping away from the abutment cut for it, which, by throwing the thrust on the tenon, would probably split it. The end of the rafter should be cut with a square butt, so that the shrinkage of the timber will not lead to any settlement.

Fig. 85.



The connection of the foot of a king-post with the tie-beam to be suspended from it is shown in fig. 85.

The king-post should be cut somewhat short, to give the power of screwing up the framing after the timber has become fully seasoned. The tie-beam may be suspended from the king-post, either by a bolt, as shown, or by a strap passed round the tie-beam and secured by iron wedges or cotters, passing through a hole in the king-post; this last is the more perfect, but at the same time the more expensive of the two methods.

Fig. 85 also shows the manner in which the feet of the struts butt upon the king-post. They are slightly tenoned to keep them in their places. The ends of a strut should be cut off as nearly square as possible, otherwise, when the timber shrinks, which it always does, more or less, the thrust is thrown upon the edge only, which splits or crushes under the pressure, and causes settlement.

This is shown out by the dotted lines on the right-hand side of the cut. The dotted lines on the opposite side of the

figure show a similar effect, produced by the shrinking of the king-post, for which there is no preventive but making it of oak, or some other hard wood. The same observations apply to the connections of the principal rafters with the top of the king-post, which are managed in a precisely similar manner.

In figures 86, 87, and 88, are shown different methods

Fig. 86.

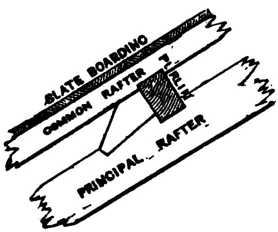
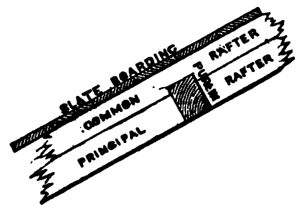
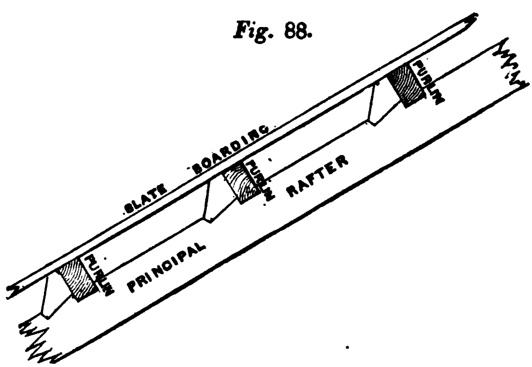


Fig. 87.



of fixing purlins, which are sufficiently explained by the figures to need no further description.

Fig. 88.



In figures 44, 45, 46, and 47, are shown the modes of framing the ends of binding joists into girders, and of connecting the ceiling joists with the binders; and as these have been already described under the head of "Floors," it is unnecessary here to say anything further on the subject.

As a general rule, all timbers should be notched down to those on which they rest, so as to prevent their being moved either lengthways or sideways. Where an upright post has to be fixed between two horizontal sills, as in the case of the uprights of a common framed partition, it is simply tenoned into them, and the tenons secured with oak pins driven through the cheeks of the mortice.

233. The carpenter requires considerable bodily strength for the handling of the timbers on which he has to work; he should have a knowledge of mechanics, that he may understand the nature of the strains and thrusts to which his work is exposed, and the best method of preventing or resisting them; and he should have such a knowledge of working drawings as will enable him, from the sketches of the architect, to set out the *lines* for every description of centering and framing that may be entrusted to him for execution.

234. In measuring carpenters' work the tenons are included in the length of the timber: this is not the case in joiners' work, in which they are allowed for in the price.

The labor in framing, roofs, partitions, floors, &c., is either valued at per square of 100 superficial feet, and the timber charged for separately, or the timber is charged as "fixed in place," the price varying according to the labor on it, as "cube fir in bond," "cube fir framed," "cube fir wrought and framed," &c. For shoring ⅓ of the value of the timber is allowed for use and waste.

JOINER.

235. The work of the joiner consists in framing and *joining* together the wooden finishings and decorations of buildings, both internal and external, such as floors, staircases, framed-partitions, skirtings, solid door and window frames, hollow or *cased* window frames, sashes and shutters, doors, columns and entablatures, chimney-pieces, &c., &c.

The joiner's work requires much greater accuracy and finish than that of the carpenter, and differs materially from it in being brought to a smooth surface with the plane wherever exposed to view, whilst in carpenters' work the timber is left rough as it comes from the saw.

236. The joiner uses a great variety of tools; the principal *cutting* tools are *saws*, *planes*, and *chisels*.

Of saws there are many varieties, distinguished from each other by their shape and by the size of the teeth.

The *ripper* has 8 teeth in 3 inches; the *half-ripper* 3 teeth to the inch; the *hand saw* 15 teeth in 4 inches; the *panel saw* 6 teeth to the inch.

The *tenon saw*, used for cutting tenons, has about 8 teeth to the inch, and is strengthened at the back by a thick piece of iron, to keep the blade from buckling. The *sash saw* is similar to the tenon saw, but is backed with brass instead of iron, and has 13 teeth to the inch. The *dovetail saw* is still smaller, and has 15 teeth to the inch.

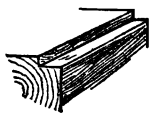
Besides the above, other saws are used for particular purposes, as the *compass saw*, for cutting circular work, and the *key-hole saw*, for cutting out small holes. The *carcase saw* is a large kind of dovetail saw, having about 11 teeth to an inch.

237. Planes are also of many kinds; those called *bench planes*—as the *jack plane*, the *trying plane*, the *long plane*, the *jointer*, and the *smoothing plane*, are used for bringing the stuff to a plane surface. The jack plane is about 18 inches long, and is used for the roughest work. The trying plane is about 22 in. long, and used after the jack plane for *trying up*, that is, taking off shavings the whole length of the stuff; whilst in using the jack plane the workman stops at every arm's-length. The *long plane* is 2 ft. 3 in. long, and is used when a piece of stuff is to be tried up very straight. The

jointer is 2 ft. 6 in. long, and is used for trying up or *shooting* the *joints*, in the same way as the trying plane is used for trying up the *face* of the stuff. The *smoothing plane* is small, being only 7½ in. long, and is used on almost all occasions for cleaning off finished work.

Rebate planes are used for sinking *rebates* (*see* fig. 89), and vary in their size and shape according to their respective uses. Rebate planes differ from bench planes in having no handle rising out of the stock, and in discharging their shavings at the side. Amongst the rebate planes may be mentioned the *moving fillister* and the *sash fillister*, the uses of which will be better understood by inspection than from any description.

Fig. 89.



Moulding planes are used for *sticking* mouldings, as the operation of forming mouldings with the plane is called. When mouldings are worked out with chisels instead of with planes, they are said to be worked *by hand*. Of the class of moulding planes, although kept separate in the tool chest, are *hollows* and *rounds* of various sizes.

There are other kinds of planes besides the above; as the *plough*, for sinking a groove to receive a projecting tongue; the *bead plane*, for sticking beads; the *snipe bill*, for forming quirks; the *compass plane* and the *forkstaff plane*, for forming concave and convex cylindrical surfaces. The shape and use of these and many other tools used by the joiner will be better understood by a visit to the joiner's shop than by any verbal description.

238. Chisels are also varied in their form and use. Some are used merely with the pressure of the hand, as the *paring chisel*; others, by the aid of the mallet, as the *socket chisel**, for cutting away superfluous stuff; and the *mortice chisel*, for cutting mortices. The *gouge* is a curved chisel.

* Named from the iron forming a socket to receive a wooden handle.

239. The joiner uses a great variety of boring tools, as the *brad-awl*, *gimlet*, and *stock and bit*. The last form but one tool, the *stock* being the handle, to the bottom of which may be fitted a variety of steel bits of different bores and shapes, for boring and widening out holes in wood and metal, as *countersinks*, *rimers*, and *taper shell bits*.

240. The *screw driver*, *pincers*, *hammer*, *mallet*, *hatchet*, and *adze*, are too well known to need description.

The *gauge* is used for drawing lines on a piece of stuff parallel to one of its edges.

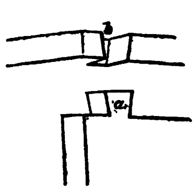
The *bench* is one of the most important of the joiner's implements. It is furnished with a vertical *sideboard*, perforated with diagonal ranges of holes, which receive the *bench pin* on which to rest the lower end of a piece of stuff to be planed, whilst the upper end is firmly clamped by the *bench screw*.

The *mitre box* is used for cutting a piece of stuff to a *mitre* or angle of 45 degrees with one of its sides.

The joiner uses for setting out and fixing his work—the straight edge, the square, the bevel or square with a shifting blade, the mitre square, the level, and the plumb rule.

In addition to the tools and implements above enumerated, the execution of particular kinds of work require other articles, as cylinders, templets, cramps, &c., the description of which would unnecessarily extend the limits of this volume.

Fig. 90.

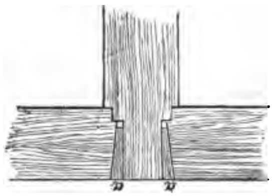


The principal operations of the joiner are sawing, planing, dovetailing, mortising, and scribing.

The manner of forming a *dovetail* is shown in fig 90. The projecting part, *a*, is called the *pin*, and the hole to receive it is called the *socket*.

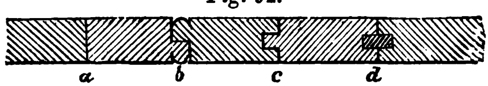
Mortising is shown in fig. 91; the projecting piece is called the *tenon*, and the hole formed to receive it the *mortice*. The tenon is sometimes *pinned* in its place with oak pins driven through the cheeks of the mortice; but in forming doors, shutters, &c., the tenon is secured with tapering wedges driven into the mortice, which is cut slightly wider at the top than at the bottom, the adhesion of the glue with which the wedges are first rubbed over, making it impossible for the tenon afterwards to draw out of its place.

Fig. 91.



241 Joints in the length of the stuff may be either square, as at *a*, fig. 92, or rebated, as at *b*, or grooved and tongued,

Fig. 92.



as at *c*, or grooved on each edge and a tongue let in, as at *d*.

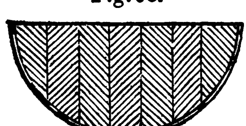
242. *Scribing* is the drawing on a piece of stuff the exact profile of some irregular surface to which it is to be made to fit: this is done with a pair of compasses, one leg of which is made to travel the irregular surface, the other to *describe* a line parallel thereto along the edge of the stuff to be cut.

243. In the execution of circular, or, as it is termed, *sweep work*, there are four different methods by which the stuff can be brought to the required curve:—

1st. It may be steamed and bent into shape.

2nd. It may be glued up in thicknesses, as shown in fig. 93, which must, when thoroughly dry, be planed true, and, if not to to be painted, covered with a thin veneer bent round it.

Fig. 93.



3rd. It may be formed in thin thicknesses, as shown in fig. 94,

bent round and glued up in a mould. This may be considered the most perfect of all the methods in use.

Fig. 94.

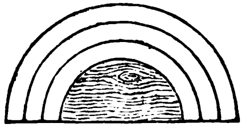
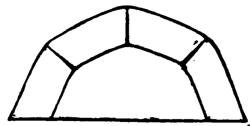


Fig. 95.

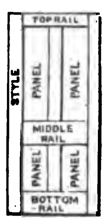


Lastly. It may be formed by sawing a number of notches on one side, as shown in fig. 95, by which means it becomes easily bent in that direction, but the curve produced by this means is very irregular, and it is an inferior mode of execution compared to the others.

When a number of boards are secured together by cross-pieces or *ledges* nailed or screwed at the back, the work is said to be *ledged* (*see* fig. 96). Ledged work is used for common purposes, as cellar doors, outside shutters, &c.

Fig. 96

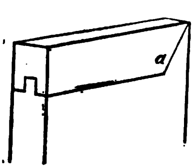
Fig. 97.



Framed work (fig. 97), consists of *styles* and *rails* mortised and tenoned together, and filled in with pannels, the edges of which fit in grooves cut in the styles and rails.

Work is said to be *clamped* when it is prevented from warping or splitting by a rail at each end, as in fig. 98 ; if the ends of the rail are cut off, as shown at *a*, it is said to be mitre clamped.

Fig 98.



There are two ways of laying floors practised by joiners. In laying what is called a *straight joint* floor, from the joints between the boards running in an unbroken line from wall to wall, each board is laid down and nailed in succession, being first forced firmly against the one last laid with a flooring cramp.

Folding floors are laid by nailing down first every fifth board rather closer together than the united widths of four boards, and forcing the intermediate ones into the space left for them by jumping over them ; this method of laying floors is resorted to when the stuff is imperfectly seasoned and is expected to shrink, but it should never be allowed in good work.

The narrower the stuff with which a floor is laid the less will the joints open, on account of the shrinkage being distributed over a greater number of joints.

The floor boards may be nailed at their edges and grooved and tongued or dowelled, if it be wished to make a very perfect floor. Dowelling is far superior to grooving and tonguing, because the cutting away the stuff to receive the tongue greatly weakens the edges of the joint, which are apt to curl.

244. Glue is an article of great importance to the joiner ; the strength of his work depending much upon its adhesive properties.

The best glue is made from the *skins* of animals ; that from the *sinewy* or *horny* parts being of inferior quality. The strength of the glue increases with the age of the animals from which the skins are taken.

Joiners' work is measured by the superficial foot, according to its description.

Floors by the square of 100 superficial feet

Handrails, small mouldings, water-trunks, and similar articles, per lineal foot.

Cantilevers, trusses, cut-brackets, scrolls to handrails, &c., are valued per piece.

Ironmongery is charged for with the work to which it is attached ; the joiner being allowed 20 per cent. profit upon the prime cost.

The principal articles of *ironmongery* used in a building consist of *nails* and *screws*, *sash pullies*, *bolts*, *hinges*, *locks*,

latches, and *sash shutter furniture*, besides a great variety of miscellaneous articles, which we have not space to enumerate.

Of the different kinds of hinges may be mentioned *hook* and *eye hinges*, for gates, coach-house doors, &c.; *butts* and *back-flaps*, for doors and shutters; *cross-garnets* of H form, which are used for hanging ledged doors, and other inferior work; ⊢ and H— hinges, whose name is derived from their shape; and *parliament* hinges.

Besides these are used *rising butts*, for hanging doors to rise over a carpet, or other impediment; *projecting butts*, used when some projection has to be cleared, and *spring hinges* and *swing centres* for self-shutting doors.

The variety of locks now manufactured is almost infinite. We may mention the *stock lock*, cased in wood, for common work. *Rim locks* which have a metal case or rim, and are attached to one side of a door: they should not be used when a door has sufficient thickness to allow of a mortice lock, as they often catch the dresses of persons passing through the doorway. *Mortice locks*, as the name implies, are those which are morticed to the thickness of a door.

The handles and escutcheons are called the *furniture* of a lock, and are made of a great variety of materials, as brass, bronze, ebony, ivory, glass, &c.

Of latches, there are the common *thumb latch*, the *bow latch*, with brass knobs, the brass *pulpit latch* and the *mortice latch*.

The *sawyer* is to the carpenter and joiner what the stone-cutter is to the mason.

The *pit saw* is a large two-handed saw fixed in a frame, and moved up and down in a vertical direction, by two men, called the top-man and the pit-man; the first of whom stands on the timber that is to be cut, the other at the bottom of the saw pit. The timber is *lined out* with a chalk line on its upper surface, and the accuracy of the work depends mainly on the top-man keeping the saw to the line, whence the pro-

verbial expression *top sawer*, meaning one who directs any undertaking.

In sawing up deals and battens into thicknesses for the joiner's use, the parallelism of the cuts is of the utmost importance, as the operation of *taking out of winding*, a piece of uneven stuff, causes a considerable waste of material, and much loss of time.

Circular saws, moved by steam-power, are now much used in large establishments, timber yards, &c., and effect a great saving of labor over the use of the pit saw, where the timbers to be cut are not too heavy to be easily handled. The saw is mounted in the middle of a stout bench, furnished with guides, by means of which the stuff to be cut is kept in the required direction, whilst it is pushed against the saw, which is the whole of the manual labor required in the operation.

SLATER.

245. The business of the slater consists chiefly in covering the roofs of houses with slates, but it has of late years being very much extended by the general introduction of sawn slate, as a material for shelves, cisterns, baths, chimney-pieces, and even for ornamental purposes.

We propose here to describe only those operations of the slater which have reference to the covering of roofs.

246. Besides the tools which are in use among other artificers, the slater uses one peculiar to his trade called the *zax*, which is a kind of hatchet, with a sharp point at the back. It is used for trimming slates, and making the holes by which they are nailed in their places.

247. Slates are laid either on boarding or on narrow battens, from 2 to 3 inches wide, the latter being the more common method, on account of its being less expensive than the other.

The nails used should be either copper or zinc; iron nails,

though sometimes used, being objectionable, from their liability to rust.

Every slate should be fastened with two nails, except in the most inferior work.

The upper surface of a slate is called its *back*, the under surface the *bed* the lower edge the *tail*, the upper edge the *head*. The part of each course of slates exposed to view is called the *margin* of the course, and the width of the margin is called the *gauge*.

The *bond* or *lap* is the distance which the lower edge of any course overlaps the slates of the second course below, measuring from the nail-hole.

In preparing slates for use, the sides and bottom edges are trimmed, and the nail-holes punched as near the head as can be done, without risk of breaking the slate, and at a uniform distance from the tail.

The lap having been decided on, the guage will be equal to half the distance from the tail to the nail-hole, less the lap. Thus a countess slate, measuring 19 in. from tail to nail, if laid with a 3 in. lap, would show a margin of $\frac{19 \text{ in.} - 3 \text{ in.}}{2} =$ 8 in. (*See* figs. 99. 100.)

Fig. 99.

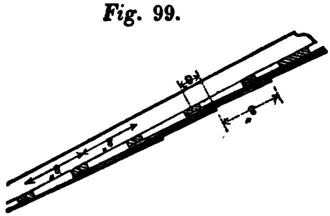
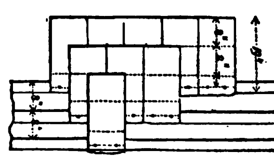


Fig. 100.



The battens are of course nailed on the rafters at the gauge to which the slate will work. If the slates are of different lengths, they must be sorted into sizes, and gauged accordingly, the smallest sizes being placed nearest the ridge. The lap should not be less than 2, and need not exceed 3 in.

It is essential to the soundness as well as the appearance of slaters' work, that the slates should all be of the same width, and the edges perfectly true.

The Welsh slates are considered the best, and are of a light sky blue color. The Westmoreland slates are of a dull greenish hue.

248. Slaters' work is measured by the square of 100 superficial feet, allowances being made for the trouble of cutting the slates at the hips, eaves, round chimneys, &c.

Slabs for cisterns, baths, shelves, and other sawn work, are charged per superficial foot, according to the thickness of the slab and the labor bestowed on the work.

Rubbed edges, grooves, &c., are charged per lineal foot.

Table of Sizes of Roofing Slates.

DESCRIPTION.	Size. Length.		Breadth.		Average gauge in inches.	No. of squares 1200 will cover.	Weight per 1200 in tons.	No. required to cover one square.	No. of nails required to one square.
	ft.	in.	ft.	in.					
Doubles . .	1	1	0	6	$5\frac{1}{2}$	2	$\frac{3}{4}$	480	480
Ladies . . .	1	4	0	8	7	$4\frac{1}{2}$	$1\frac{1}{4}$	280	280
Countesses	1	8	0	10	9	7	2	176	352
Duchesses	2	0	1	0	$10\frac{1}{2}$	10	3	127	254
Imperials .	2	6	2	0	a ton will cover $2\frac{1}{4}$ to $2\frac{1}{2}$ squares.				
Rags and Queens	3	0	2	0					
Westmerelands, of various sizes.									

Inch slab per superficial weighs 14 lbs.

PLASTERER.

249. The work of the plasterer consists in covering the brickwork and naked timber walls, ceilings, and partitions

with plaster, to prepare them for painting, papering, or distempering; and in forming cornices, and such decorative portions of the finishings of buildings as may be required to be executed in plaster or cement.

250. The plasterer uses a variety of tools, of which the following are the principal ones :—

The *drag* is a three-pronged rake, used to mix the hair with the mortar in preparing coarse stuff.

The *hawk* is a small square board for holding stuff on, with a short handle on the under side.

Trowels are of two kinds, the *laying and smoothing tool,* with which the first and the last coats are laid, and the *gauging trowel,* used for gauging fine stuff for cornices, &c. ; these are made of various sizes, from 3 to 7 in. long.

Of *floats,* which are used in *floating,* there are three kinds, viz., the *Derby,* which is a rule of such a length as to require two men to use it ; the *hand float,* which is used in finishing stucco ; and the *quirk float,* which is used in floating angles.

Moulds, for running cornices, are made of sheet copper, cut to the profile of the moulding to be formed, and fixed in a wooden frame.

Stopping and *picking out tools* are made of steel, 7 or 8 in. long, and of various sizes. They are used for modeling, and for finishing mitres and returns to cornices.

251. *Materials.—Coarse stuff,* or lime and hair, as it is usually called, is similar to common mortar, with the addition of hair from the tanners' yard, which is thoroughly mixed with the mortar by means of the drag.

Fine stuff is made of pure lime, slaked with a small quantity of water, after which, sufficient water is added to bring it to the consistence of cream.

It is then allowed to settle, and the superfluous water being poured off, it is left in a binn or tub to remain in a semifluid state until the evaporation of the water has brought

it to a proper thickness for use. In using fine stuff for setting ceilings, a small portion of white hair is mixed with it.

Stucco is made with fine stuff, and clean-washed sand. This is used for finishing work intended to be painted.

Gauged stuff is formed of fine stuff mixed with plaster of Paris, the proportion of plaster varying according to the rapidity with which the work is required to set. Gauged stuff is used for running cornices and mouldings.

Enrichments, such as pateras, centre flowers for ceilings, &c., are first modeled in clay, and afterwards cast of plaster of Paris in wax or plaster moulds. Papier maché ornaments also are much used, and have the advantage of being very light, and being easily and securely fixed with screws.

The variety of compositions and cements made use of by the plasterer is very great. Roman cement, Portland cement, and lias cement, are the principal ones used for coating buildings externally. Martin's and Keene's cements are well adapted for all internal plastering where sharpness, hardness, and delicate finish are required.

252. *Operations of Plastering.*—When brick-work is plastered, the first coat is called *rendering.*

In plastering ceilings and partitions, the first operation is *lathing.* This is done with *single, one and a half,* or *double* laths; these names denoting their respective thicknesses. Laths are either of oak or fir; if the former, wrought-iron nails are used, but cast-iron may be employed with the latter. The thickest laths are used for ceilings, as the strain on the laths is greater in a horizontal than in an upright position.

Pricking up is the first coat of plastering of course stuff upon laths; when completed, it is well scratched over with the end of a lath, to form a key for the next coat.

Laid work consists of a simple coat of coarse stuff over a wall or ceiling.

Two-coat work is a cheap description of plastering, in which the first coat is only roughed over with a broom, and afterwards *set* with fine stuff, or with gauged stuff in the better descriptions of work.

The laying on of the second coat of plastering is called *floating*, from its being *floated*, or brought to a plane surface with the float.

The operation of floating is performed by surrounding the surface to be floated with narrow strips of plastering, called screeds, brought perfectly upright, or level, as the case may be, with the level or plumb-rule; thus, in preparing for floating a ceiling, nails are driven in at the angles, and along the sides, about 10 ft. apart, and carefully adjusted to a horizontal plane, by means of the level. Other nails are then adjusted exactly opposite to the first, at a distance of 7 or 8 in. from them. The space between each pair of nails is filled up with coarse stuff, and leveled with a hand float; this operation forms what are called *dots*. When the dots are sufficiently dry, the spaces between the dots are filled up flush with coarse stuff, and floated perfectly true with a floating rule; this operation forms a *screed*, and is continued until the ceiling is surrounded by one continuous screed, perfectly level throughout. Other screeds are then formed, to divide the work into bays about 8 ft. wide, which are successively filled up flush, and floated level with the screeds.

The screeds for floating walls are formed in exactly the same manner, except that they are adjusted with the plumb-rule instead of the level.

After the work has been brought to an even surface with the floating rule, it is gone over with the hand float, and a little soft stuff, to make good any deficiencies that may appear.

The operation of forming screeds and floating work, which is not either vertical or horizontal, as a plaster floor laid with a fall, is analogous to that of taking the face of a stone out of winding with chisel-drafts and straight edges in stone-

cutting; the principle being in each case to find three points in the same plane, from which to extend operations over the whole surface.

Setting.—When the floating is about half dry, the setting or finishing coat of fine stuff is laid on with the smoothing trowel, which is alternately wetted with a brush and worked over with the smoothing tool, until a fine surface is obtained.

Stucco is laid on with the largest trowel, and worked over with the hand float, the work being alternately sprinkled with water, and floated until it becomes hard and compact, after which it is finished by rubbing it over with a dry stock brush.

The water has the effect of hardening the face of the stucco, so that, after repeated sprinklings and trowelings, it becomes very hard, and smooth as glass.

253. The above remarks may be briefly summed up as follows. The commonest kind of work consists of only one coat, and is called *rendering*, on brick-work, and *laying*, if on laths. If a second coat be added, it becomes two-coat work, as *render-set*, or *lath lay* and *set*. When the work is floated, it becomes three-coat work, and is *render*, *float*, and *set*, for brick-work, and *lath*, *lay*, *float*, and *set*, for ceilings and partitions; ceilings being set with fine stuff, with a little white hair, and walls intened for paper with fine stuff and sand; stucco is used where the work is to be painted.

Rough stucco is a mode of finishing staircases, passages, &c., in imitation of stone. It is mixed with a large proportion of sand, and that of a coarser quality than troweled stucco, and is not smoothed, but left rough from the hand float, which is covered with a piece of felt, to raise the grit of the sand, to give the work the appearance of stone.

Rough cast is a mode of finishing outside work, by dashing over the second coat of plastering, whilst quite wet, a layer of rough-cast, composed of well-washed gravel, mixed up with pure lime and water, till the whole is in a semifluid state.

Pugging is lining the spaces between floor joists with coarse stuff, to prevent the passage of sound, or between two stones, and is done on laths or rough boarding.

In the midland districts of England, reeds are much used instead of laths, not only for ceilings and partitions, but for floors, which are formed with a thick layer of coarse gauged stuff upon reeds. Floors of this kind are extensively used about Nottingham; and, from the security against fire afforded by the absence of wooden floors, Nottingham houses are proverbially fire-proof.

254. Plasterer's work is measured by the superficial yard; cornices by the superficial foot; enrichments to cornices by the lineal fool; and centre flowers and other decorations at per piece.

MEMORANDA.

Lathing.—One bundle of laths and 384 nails will cover 5 yards.

Rendering.—187½ yards require 1½ hundred of lime, 2 double loads of sand, and 5 bushels of hair.

Floating requires more labor, but only half as much material as rendering.

Setting.—375 yards require 1½ hundred of lime, and 5 bushels of hair.

Render set.—100 yards require 1½ hundred of lime, 1 double load of sand, and 4 bushels of hair. Plasterer, laborer, and boy, 3 days each.

Lath, lay, and *set.*—130 yards of lath, lay, and set, require 1 load of laths, 10,000 nails, 2½ hundred of lime, 1½ double load of sand, and 7 bushels of hair. Plasterer, laborer, and boy, 6 days each.

SMITH AND IRONFOUNDER.

255. The smith furnishes the various articles of wrought-iron work used in a building; as pileshoes, straps, screw-

bolts, dog-irons, chimney bars, gratings, wrought-iron railing, and wrought-iron balustrades for staircases. Wrought iron was formerly much used for many purposes, for which cast iron is now almost exclusively employed; the improvements effected in casting during the present century having made a great alteration in this respect.

The operations of the ironfounder have been described in Section II. of this volume, and therefore we have only here to enumerate some of the principal articles which are furnished by him.

Besides cast-iron columns, girders, and similar articles which are cast to order, the founder supplies a great variety of articles which are kept in store for immediate use; as cast-iron gratings, balconies, rain-water pipes and guttering, air traps, coal plates, stoves, stable fittings, iron sashes, &c.

Both wrought and cast-iron work are paid for by weight, except small articles kept in store for immediate use, which are valued per piece.

		lbs.
One cubic foot of	cast iron weighs about	450
Ditto	wrought ,,	475
Ditto	closely hammered	485

256. The *Coppersmith* provides and lays sheets of copper for covering roofs; copper gutters, and rainwater pipes; washing and brewing coppers; copper cramps and dowels for stonemasons' work; and all other copper work in a building; but the cost of the material in which he works prevents its general use; and the washing copper is frequently the only part of a building which requires the aid of this artificer. Sheet copper is paid for by the superficial foot, according to weight, and pipes and gutters per lineal foot; copper in dowels, bolts, &c., at per pound.

257. *Warming apparatus, steam* and *gas fittings*, and similar kinds of work, are put up by the mechanical engineer, who also manufactures a great variety of articles, which are

purchased in parts, and put together and fixed by the plumber, as pumps, taps, water-closet apparatus, &c.

258. The *bell-hanger* provides and hangs the bells required for communicating between the different parts of a building, and connects them with their *pulls*, or handles, by means of cranks and wires.

The action of the pull upon the bell should be as direct, and effected with as few cranks as possible ; and the cranks and wires should be concealed from view, both to protect them from injury, and on account of their unsightly appearance.

In all superior work, the wires are conducted along concealed tubes, fixed to the walls before the plasterer's work is commenced. The simplest way of arranging the wires is to carry them up in separate tubes to the roof, where they may all be conducted to one point, and brought down a chase in the walls to the part of the basement where the bells are hung, By this means very few cranks are required, and a broken wire can be replaced at any time without trouble.

259. Bell-hangers' work is paid for by the number of bells hung ; the price being determined by the manner in which the work is executed. The *furniture* to the pulls is charged in addition, at per piece.

PLUMBER.

260. The work of the plumber chiefly consists in laying sheet lead on roofs, lining cisterns, laying on water to the different parts of a building, and fixing up pumps and water closets.

261. The plumber uses but few tools, and those are of a simple character ; the greater number of them being similar to those used by other artificers, as *hammers*, *mallets*, *planes*, *chisels*, *gouges*, *files*, &c. The principal tool peculiar to the

trade of the plumber is the *bat*, which is made of beech, about 18 in. long, and is used for dressing and flattening sheet lead. For soldering also the plumber uses iron ladles, of various sizes, for melting solder, and *grozing irons*, for smoothing down the joints.

262. The sheet lead used by the plumber is either *cast* or *milled*, the former being generally cast by the plumber himself out of old lead taken in exchange ; whilst the latter, which is cast lead, flattened out between rollers in a flatting mill, is purchased from the manufacturer. Sheet lead is described according to the weight per superficial foot, as 5-lb. lead, 6-lb. lead, &c.

Lead pipes, if of large diameter, are made of sheet lead, dressed round a wooden core, and soldered up.

Smaller pipes are cast in short lengths, of a thickness three or four four times that of the intended pipe, and either *drawn* or *rolled* out to the proper thickness.

Soft Solder is used for uniting the joints of lead-work. It is made of equal parts of lead and tin, and is purchased of the manufacturer by the plumber, at a price per lb., according to the state of the market.

263. *Laying of Sheet Lead.*—In order to secure lead-work from the injurious effects of contraction and expansion, when exposed to the heat of the sun, the plumber is careful not to confine the metal by soldered joints or otherwise. All sheet lead should be laid to a sufficient *current*, to keep it dry ; a fall of 1 in. in 10 ft. is sufficient for this purpose, if the boarding on which the lead is laid be perfectly even. Joints in the direction of the current are made by dressing the edges of the lead over a wooden *roll*, as shown in fig. 101.

Joints in the length of the current are made with *drips*, as shown on the left- hand-side of fig. 102.

Fig. 101.

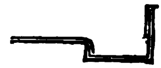


Fig. 102.

Flashings are pieces of lead *turned down* over the edges of the other lead-work, which is *turned up* against a wall, as shown on the right-hand side of fig. 107, and serve to keep the wet from finding its way between the wall and the lead. The most secure way of fixing them is to build them into the joints of the brickwork, but the common method is to insert them about an inch into the mortar joint, and to secure them with wall hooks and cement. (*See* fig. 102.)

264. A very important part of the business of the plumber consists in fitting up cisterns, pumps, and water-closet apparatus, and in laying the different services and wastes connected with the same.

265 Plumber's work is paid for by the cwt., milled lead being rather more expensive than cast.

Lead pipes are charged per foot lineal, according to size.

Pumps and water-closet apparatus are charged at so much each, according to description; as also, basins, air traps, washers and plugs, spindle valves, stop-cocks, ball-cocks, &c.

Table of the Weight of Lead Pipes, per yard.

Bore.	lb.	oz.
½ inch	3	3
¾ "	5	7
1 "	8	0
1¼ "	11	0
1½ "	14	0
2 "	21	0

ZINC WORKER.

266. The use of sheet lead has been to a certain extent superseded by the use of sheet zinc, which, from its cheapness and lightness, is very extensively used for almost all

purposes to which sheet lead is applied. It is, however, a very inferior material, and not to be depended upon. The laying of it is generally executed by the plumber; but the working of zinc, and manufacturing of it into gutters, rain-water pipes, chimney cowls, and other articles, is practised as a distinct business.

GLAZIER.

267. The business of the glazier consists in cutting glass, and fixing it into lead-work, or sashes. The former is the oldest description of glazing, and is still used, not only for cottage windows, and inferior work, but for church windows, and glazing with stained glass, which is cut into pieces of the required size, and set in a leaden framework; this kind of glazing is called *fretwork.*

268. *Glazing in sashes* is of comparatively modern introduction. The sash-bars are formed with a *rebate* on the outside, for the reception of the glass, which is *cut into* the rebates, and firmly *bedded* and *backputtied* to keep it into its place. Large squares are also *sprigged,* or secured with small brads driven into the sash bars.

269. *Glazing in lead-work* is fixed in leaden rods, called *cames,* prepared for the use of the glazier by being passed through a glazier's vice, in which they receive the grooves for the insertion of the glass. The sides or cheeks of the grooves are sufficiently soft to allow of their being turned down to admit the glass, and again raised up and firmly pressed against it after its insertion.

For common lead-work, the bars are soldered together, so as to form squares or diamonds. In fretwork, the bars, instead of being used straight, are bent round to the shapes of the different pieces of glass forming the device—lead-work is strengthened by being attached to *saddle bars* of iron, by leaden bands soldered to the lead-work, and twisted round the iron.

Putty is made of pounded whiting, beaten up with linseed oil into a tough, tenaceous cement.

270. The principal tool of the glazier is the *diamond*, which is used for cutting glass. This tool consists of an unpolished diamond fixed in lead, and fastened to a handle of hard wood.

The glazier uses a *hacking out knife*, for cutting out old putty from broken squares ; and the *stopping knife*, for laying and smoothing the putty when *stopping-in* glass into sashes.

For setting glass into lead-work the *setting knife* is used.

Besides the above, the glazier requires a square and straight edges, a rule and a pair of compasses, for dividing the tables of glass to the required sizes.

Also a hammer and brushes, for sprigging large squares, and cleaning off the work.

The *glazier's vice* has already been mentioned ; the *latterkin* is a pointed piece of hard wood, with which the grooves of the *cames* are cleared out and widened for receiving the glass.

271. Cleaning windows is an important branch of the glazier's business in most large towns ; the glazier taking upon himself the cost of repairing all glass broken in cleaning.

272. Glaziers' work is valued by the superficial foot, the price increasing with the size of the squares. Irregular panes are taken of the extreme dimensions each way.

Crown glass is *blown* in circular *tables* from 3 ft. 6 in. to 5 ft. diameter, and is sold in *crates*, the number of tables in a crate varying according to the quality of the glass.

A crate	contains	12	tables of	best quality.
„	„	15	„	second do.
„	„	18	„	third do.

Plate glass is *cast* on large plates on horizontal tables, and afterwards polished.

The manufacture of sheet or spread glass, which was formerly considered a very inferior article, has of late years been much improved; much is now sold, after being polished, under the name of Patent Plate.

PAINTER, PAPERHANGER, AND DECORATOR.

273. The business of the house-painter consists in covering, with a preparation of white lead and oil, such portions of the joiner's, smith's, and plasterer's work as require to be protected from the action of the atmosphere. Decorative painting is a higher branch, requiring a knowledge of the harmony of colors, and more or less of artistic skill, according to the nature of the work to be executed. The introduction of fresco painting into this country as a mode of internal decoration has led to the employment of some of the first artists of the day in the embellishment of the mansions of the wealthy; and the example thus set will, no doubt, be extensively followed.

274. The principal materials used by the painter are *white lead*, which forms the basis of almost all the colors used in house-painting; *linseed oil* and *spirits of turpentine*, used for mixing and diluting the colors; and *dryers*, as litharge, sugar of lead, and white vitriol, which are mixed with the colors to facilitate their drying *Putty*, made of whiting and linseed oil, is used for *stopping* or filling up nail holes, and other vacuities, in order to bring the work to a smooth face.

275. The painter's tools are few and simple; they consist of the *grinding stone* and *muller*, for grinding colors; *earthen pots*, to hold colors; *cans*, for oil and turps; a *pallet knife*, and *brushes* of various sizes and descriptions.

276. In painting wood-work, the first operation consists in *killing* the knots, from which the turpentine would otherwise exude and spoil the work. To effect this, the knots are

covered with fresh slaked lime, which dries up and burns out the turpentine. When this has been on twenty-four hours, it is scraped off, and the knots painted over with a mixture of red and white lead, mixed with glue size. After this they are gone over a second time with red and white lead, mixed with linseed oil. When dry, they must be rubbed perfectly smooth with pumice stone, and the work is ready to receive the priming coat. This is composed of red and white lead, well diluted with linseed oil. The nail holes and other imperfections are then stopped with putty, and the succeeding coats are laid on, the work being rubbed down between each coat, to bring it to an even surface. The first coat after the priming is mixed with linseed oil and a little turpentine. The second coat with equal quantities of linseed oil and turpentine. In laying on the second coat, where the work is not to be finished white, an approach must be made to the required color. The third coat is usually the last, and is made with a base of white lead, mixed with the requisite color, and diluted with one-third of linseed oil to two-thirds of turpentine.

Painting on stucco, and all other work in which the surface is required to be without gloss, has an additional coat mixed with turpentine only, which, from its drying of one uniform *flat* tint, is called a flatting coat.

If the knots show through the second coat, they must be carefully covered with silver leaf.

Work finished as above described would be technically specified as knotted, primed, painted three oils, and flatted.

Flatting is almost indispensable in all delicate interior work, but it is not suited to outside work, as it will not bear exposure to the weather.

277. Painting on stucco is primed with boiled linseed oil, and should then receive at least three coats of white lead and oil, and be finished with a flat tint. The great secret of success in painting stucco is that the surface should be

perfectly dry ; and, as this can hardly be the case in less than two years after the erection of a building, it will always be advisable to finish new work in distemper, which can be washed off whenever the walls are sufficiently dry to receive the permanent decorations

278. *Graining* is the imitation of the grain of various kinds of woods, by means of *graining tools*, and, when well executed, and properly varnished, has a handsome appearance, and lasts many years. The term graining is also applied to the imitation of marbles.

279. Clear coling (from *claire colle*, i. e. transparent size, Fr.), is a substitution of size for oil, in the preparation of the priming coat. It is much resorted to by painters on account of the ease with which a good face can be put on the work with fewer coats than when oil is used ; but it will not stand damp, which causes it to scale off, and it should never be used except in repainting old work, which is greasy or smoky, and cannot be made to look well by any other means.

280. *Distempering* is a kind of painting in which whiting is used as the basis of the colors, the liquid medium being size ; it is much used for ceilings and walls, and always will require two, and sometimes three coats, to give it a uniform appearance.

281. Painters' work is valued per superficial yard, according to the number of coats, and the description of work, as common colors, fancy colors, party colors, &c.

Where work is cut in on both edges, it is taken by the lineal foot. In measuring railings, the two sides are measured as flat work. Sash frames are valued per piece, and sashes at per dozen squares.

282. The manufacture of scagliola, or imitation marble, is a branch of the decorator's business, which is carried to very great perfection.

Scagliola is made of plaster of Paris and different earthy colors, which are mixed in a trough in a moist state, and blended together until the required effect is produced, when the composition is taken from the trough, laid on the plaster ground, and well worked into it with a wooden beater, and a small gauging trowel. When quite hard, it is smoothed, scraped, and polished, until it assumes the appearance of marble.

Scagliola is valued at per superficial foot, according to the description of marble imitated, and the execution of the work.

283. Gilding is executed with leaf gold, which is furnished by the gold-beater in books of 25 leaves, each leaf measuring 3⅛ in. by 3 in. The parts to be gilded are first prepared with a coat of gold size, which is made of Oxford ochre and fat oil.

284. The operations of the paper-hanger are too simple to require description.

A piece of paper is 12 yards long, and is 20 ins. wide, when hung, and covers 6 ft. superficial; hence the number of superficial feet that have to be covered, divided by 60, will give the number of pieces required.

Paper-hangers' work is valued at per piece, according to the value of the paper.

The trades of the plumber, glazier, painter, paper-hanger, and decorator are often carried on by the same person.

DRAINAGE.

285. The principal classes of buildings as subjects for water supply and drainage, are—1. Dwellings; 2. Manufactories; and 3. Public buildings.

There is no certain date upon which to calculate the extent of the arrangement to be provided for the joint purposes of supplying water and discharging sewerage. In England the

calculations of water companies are usually based upon the rental paid for each house as an index to the consumption of water within it, and in this way they recognize an almost infinite number of classes.

286. It is estimated that 20 gallons of water is the average daily quantity for each inhabitant of a town, and that this quantity is sufficient to allow also for an ordinary proportion of manufacturing operations, for the supply of public buildings, and for the extinction of fires. It is estimated that a bulk of water measuring 6 feet in length by 1½ feet in width and 1 ft. in depth, will suffice for the ablution of one person in the baths. This quantity will equal 9 cubic feet, or about 54 gallons.

287. Sewers and drains were formerly devised with the single object of making them *large enough*, by which it was supposed that their full efficiency was secured. But sluggishness of the action is now recognized as the certain consequence of excess equally as of deficiency of declination. A small stream of liquid matter extended over a wide surface, and reduced in depth in proportion to this width, suffers retardation from the want of declivity in the current. Hence a drain which is disproportionally large in comparison to the amount of drainage is concentrated within a more limited channel, a greater rapidity is produced, and every addition to the contents of the aids by the full force of its gravity in propelling the entire quantity forward to the point of discharge.

288. There are four conditions which are to be regarded as indispensable in the construction of all drains from all buildings whatsoever. These conditions are—First. That the entire length of drain is to be constructed and maintained with *sufficient declivity* towards the discharge into the sewer to enable the average proportion and quantity of liquid and solid matters committed to it to maintain a *constant* and *uninterrupted motion*, and that stagnation shall never occur.

Second. That the entire length of drain is to be constructed and maintained in a condition of *complete impermeability*, so that no portion of the matters put into it should escape from it. Third. That the head of the drain shall be so efficiently trapped that no gaseous or volatile properties or products can possibly arise from its contents. Fourth. That the lower extremity of the drain, or the point of its communication with the sewer, shall be so properly, completely, and durably formed, that no interruption to the flow of the drainage or escape shall take place, and that no facility shall be offered for the upward progress of the sewerage in case the sewer becomes surcharged, and thus tends to produce such an effect.

289. The common occuption of the basement stories of houses, as kitchens and water closets, has made it appear desireable to depress the drains and sewers, in order to receive the refuse matters below the level of these basements; but as this object involves one or both of the evils we have pointed out, viz: deficient declivity and consequent stagnation in the drains, and a general system of sewers sunk so deeply in the ground that incomparable expense and difficulty are created in construction, access, and repairs, the purpose of basement draining should be abandoned, and practicable methods sought of delivering the entire drainage at the level of the surface ground.

290. Brick-work does not seem to be peculiarly fitted for drains. It requires smoothness and tightness. Stoneware, is more economical for this purpose than iron tubing, and is entirely free from the chance of corrosion and permeability. By glazing the interior surface, moreover, tubes of this ware are made peculiarly suitable for adoption in forming drains; and carefully made socket joints laid in the direction of the current are cheaply executed, if moulded conically and luted with a little cement of the best quality. The size of the drain pipes has to be graduated according to the quantity to be passed through them.

291. The trapping of the head of the drain, so as to prevent the ascent of smell and impure gas from the drain into the building, is an indispensable requirement in draining apparatus. Simplicity of construction and permanence of action are, of course, required, with the least original outlay at which these qualities can be obtained.

292. The lower connection of the house drain with the public sewer is the last point of importance to which we allude. A perfect construction of this portion of the work has always been recognised as an essential feature of good drainage. The level of the bed of the drain must be kept as high as possible above that of the receiving sewer. If the sewer be also constructed of the glazed stone ware piping, lengths of it may be introduced at convenient intervals, having outlet sockets for receiving the ends of the house-drains, and being slightly tapered or conical in form will be readily jointed with a little of the best cement. If the sewer be constructed of brickwork, a good joint will be obtained by introducing a separate socket of stone-ware to receive the house-drain pipe, and formed with a flange at the other end to surround and cover the opening in the sewer, which can then be made good with a ring of cement carefullly applied.

Means of access to house-drains are always desirable in arranging the details of the apparatus.

PAINTS.

293. Before you commence to paint a building, all holes, nail heads, and indentations should be filled in with putty. The *priming* should then be put on. The color will, of course, depend on the color of the paint to be put on. After the priming is perfectly dry, follow with another coat of priming, or a coat of paint.

Nut oil is better than linseed oil, to be mixed with paint, that requires exposure to the weather.

294. Painters require a *paint pot* in which to carry their paint, *brushes*, with which to put it on, *pencils*, or small, soft brushes for fine work, a *palette*, or small, thin, oval shaped board on which to spread paint when delicate work is being done, a *moll stick*, with which to steady the hand.

We cannot give recipes for making the various kinds of varnish and paints in this work.

SECTION V.

WORKING DRAWINGS, SPECIFICATIONS, ESTIMATES, AND CONTRACTS.

295. The erection of buildings of any considerable magnitude is usually carried on under the superintendence of a professional architect, whose duties consist in the preparation of the various working drawings and specifications that may be required for the guidance of the builder; in the strict supervision of the work during its progress, to insure that his instructions are carried out in a satisfactory manner; and in the examination and revision of all the accounts connected with the works.

This brief enumeration of the duties of an architect will suffice to show how many qualifications are required in one who aims at being thoroughly competent in his profession. He must unite the taste of the artist with the science and practical knowledge of the builder, and must be at the same time conversant with mercantile affairs, and counting-house routine, in order that he may avoid involving his employer in the trouble and expense attendant on disputed accounts, which generally are the result of the want of a clear and explicit understanding, on the part of the builder, of the obligations and responsibilities of engagements based upon the incomplete drawings, or vaguely worded specifications of an incompetent architect.

296. The profession of the architect and the trade of the builder are sometimes carried on by the same person: but this union of the directive and executive functions is not to be recommended; in the first place, because the duties of the workshop and the builder's yard leave little time for the study of the higher branches of architectural knowledge;

and, in the second place, because the absence of professional control will always be a strong temptation to a contractor to prefer his own interests to those of his employer, however competent he may be to design the buildings with the execution of which he may be charged.

During the present century, the impulse given to our arts and manufactures, and the improvements effected in the internal communications of the country, have given rise to the execution of many extensive works requiring for their construction a large amount of mechanical and scientific knowledge; in consequence of which a new and most important profession has sprung up during the last thirty years, occupying a middle position between those of architecture and mechanical engineering, viz., that of the civil engineer. The practice of the architect and of the civil engineer so closely approximate in many respects, that it is difficult strictly to draw the line of demarcation between them; but it may be said in general terms that whilst the one is chiefly engaged in works of civil and decorative architecture, such as the erection of churches, public buildings, and dwelling-houses, the talent of the other is principally called forth in the art of construction on a large scale, as applied to retaining walls, bridges, tunnels, light-houses, &c., and works connected with the improvements of the navigation and internal communications of the country.

297. The business of the surveyor is often carried on as a distinct branch of architectural practice; and, as the title of surveyor is often appropriated to those who have no real claim to it, a few words on a surveyor's duties may not be here out of place.

Surveyors may be divided into three classes: land surveyors, engineering surveyors, and building surveyors.

The business of an engineering surveyor, as distinguished from that of a land surveyor, chiefly consists in the preparation of accurate plans, sections, and other data relative to

the intended sites of large works, which may be required by the architect or engineer preparatory to making out his working drawings, and in conducting leveling operations for drainage works, canals, railways, &c.

The building surveyor prepares, from the drawings and specifications of the architect or the engineer, bills of quantities of intended works, for the use of the builder on which to frame his estimates ; and, in the case of contracts, these bills of quantities form the basis of the engagements entered into by the builder and his employer, the surveyor being pecuniarly answerable for any omissions. The surveyor is also employed in the measurement of works already executed or in progress ; in the latter case, for the purpose of ascertaining the advances to be made at stated intervals, and is engaged generally in all business connected with builders' accounts.

298. The following is the general routine of proceedings in the case of large works. It will readily be understood that in small works subdivision of labor is not carried to such an extent, the architect superintending the works himself, without the aid of a clerk of works, and the builders taking out their own quantities.

I. The general design having been approved of, and the site fixed upon, an exact plan is made of the ground, the nature of the foundation examined, and all the levels taken that may be required for the preparation of the working drawings.

II. The architect makes out the working drawings, and draws up the specification of the work.

III. A meeting is held of builders proposing to tender for the execution of the proposed works, called either by public advertisement or private invitation, at which a surveyor is appointed in their behalf to take out the quantities. Sometimes two surveyors are appointed, one on the part of the builders, and one on the part of the architect, who take

out the quantities together, and check each other as they proceed.

IV. The surveyor having furnished each party proposing to tender with a copy of the bills of quantities, the builders prepare their estimates, and meet a second time to give in their tenders, after which the successful competitor and the employer sign a contract, drawn up by a solicitor, binding the proper execution of the works, and the other to the payment of the amount of their cost at such times and in such sums as may be set forth in the specification.

V. The work is then set out,* and carried on under the constant direction of a foreman on the part of the builder, and on the part of the architect under the superintendence of an inspector or clerk of works, whose duty it is to be constantly on the spot to check the quality and quantity of material used, to see to the proper execution of the work, and to keep a record of every deviation from the drawings that may be rendered necessary by the wishes of the employer, or by local circumstances over which the architect has no control.

The work is measured up at regular intervals, and payments made on account to the builder, upon the architect's certificate of the amount of work done.

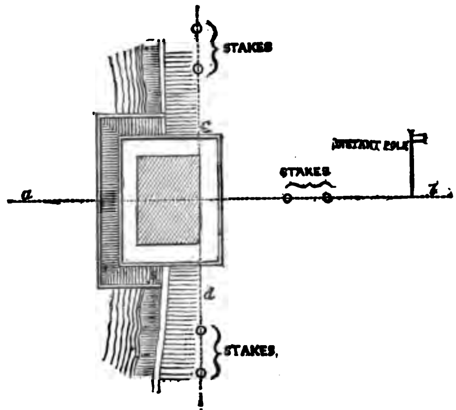
VI. The work being completed, the extras and omissions are set against each other, and the difference added to or deducted from the amount of the contract, and the whole business is concluded by the architect giving a final certificate for the payment of the balance due to the builder.

---

* *On Setting out Work.*—The determination of the exact position of an intended building being sometimes difficult to accomplish, a few remarks on the subject may be acceptable.

The setting out of the leading lines is simple enough on level ground, where nothing occurs to interrupt the view, or to prevent the direct measurement of the required distances; but to perform this operation at the bottom of a foundation pit, blocked up with balks and shores and ankle-deep in slush, requires a degree of practice and patience not always to be met with. Let us take a simple

Fig. 103.



299. *Plan of Site.*—In preparing the plan of the site of the proposed works, the operations of the surveyor will

---

case, such as the putting in the abutment of a bridge or a viaduct, any error in the position of which would render the work useless (see fig. 103). The leading lines having been laid down on the drawings, the first thing to be done, before breaking ground, is to set out the centre line very carefully with a theodolite and ranging rods for a considerable distance on each side of the work, and to fix its position by erecting poles, planed true and placed perfectly upright, in some part of the line where there is no chance of their being disturbed.

Next, the exact position of the abutment on the centre line would be decided upon, and fixed by setting out another line at right angles to the first, as *c d*. which would also be extended beyond the works, and its position fixed by driving in stakes, the exact position of the line on the head of the stake being marked by a saw cut.

These guiding lines having now been permanently secured, the plan of the abutment may be set out on the ground, the dams driven, and the earth got out to the required depth. By the time the excavation is ready for commencing the work, it generally presents a forest of stays, struts, and shores that would defy any attempt at setting out the work on its own level; it must therefore be set out at the top of the dam, and the points transferred or *dropped*, as follows :—

First, the position of the centre line is ascertained by reference to the poles, and nails being driven into the timbers at the sides of the dam, a fine line is strained across; the position of the line *c d* is found, and a second line strained across in the same way. In a similar manner other lines are strained from side to side at the required distances, the length being measured from the line *c d*, and the widths from *a b*, until the outline of the foundation course is found; the angle points are then transferred to the bottom of the excavation by means of plumb-lines, and the work is commenced, its accuracy being easily tested by measurements from the lines *a b* and *c d*, until it is so far advanced as to render this unnecessary.

generally have to be extended beyond the spot of ground on which the building is to stand. The frontages of the adjacent buildings, and the position of all existing or contemplated sewers, drains and water-courses, should be correctly ascertained and laid down. Sketches drawn to scale of the architectural sketches of the adjacent buildings, if in town, and accurate outline sketches of the *incidents* of the locality of the intended operations, if in the country, should accompany the plan, that the architect may try the effect of his design before its actual execution renders it impossible to remedy its faults.

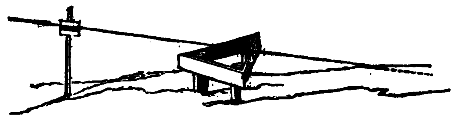
By the careful study of all these data the architect may hope to succeed in making his works harmonize with the objects that surround them; without them, failure on this head is almost a certainty.

300. *Levels.*—Where the irregularities of the ground are considerable, it is necessary to ascertain the variations of the surface before the depth of the foundations and the position of the floors can be decided upon.

It also frequently happens that the levels of the floors and other leading lines, in a new building, are regulated by the capabilities of sewerage or drainage, or by the heights of other buildings with which the new work will ultimately be connected, as in the case of new streets. It therefore becomes of importance to have simple and accurate means of ascertaining and recording the relative heights of different points. For this purpose both the spirit level and the mason's level are used.

301. Where the ground to be leveled over is limited in extent, and the variations of level do not exceed 12 feet, the heights of any points may be found with the mason's level in the following manner. (*See* fig. 104.)

Fig. 104.



In a convenient place, near the highest part of the ground, drive three stout stakes at equal distances from each other, and nail to them three pieces of stout plank, placed as shown in the cut, their upper edges being adjusted to the same horizontal plane by means of the mason's level. The level being then placed on this frame, an assistant proceeds to the first point of which the height is required, holding up a rod with a sliding vane, which he raises or lowers in obedience to the directions of the surveyor, until it coincides with a pair of sights fixed at the bottom of the level; the height of the vane will then be the difference of level between the top of the leveling frame, and the place where the staff was held up.

302. The above and similar methods will suffice for taking levels in a rough way for the ordinary purposes of the builder; but where great accuracy is requisite, or where the levels have to be extended over a considerable distance, as is often the case in drainage works, the use of a more perfect contrivance is necessary, and the spirit level is the instrument principally used for this purpose.

The spirit level consists of a telescope mounted on a portable stand, and furnished with screw adjustments, by means of which it can be made to revolve in a horizontal plane, any deviation from which is indicated by the motion of an air-bubble in a glass tube fixed parallel to the telescope.

The eye-piece of the telescope is furnished with cross-wires, as they are technically termed, made of spiders' thread, of which the use will be presently explained.

303. The leveling staff, now in common use, is divided

into feet, tenths, and hundredths, in a conspicuous manner, so that, with the help of the glass, every division can be distinctly seen at the distance of one hundred yards or more. The mode of conducting the operation of leveling is as follows :—

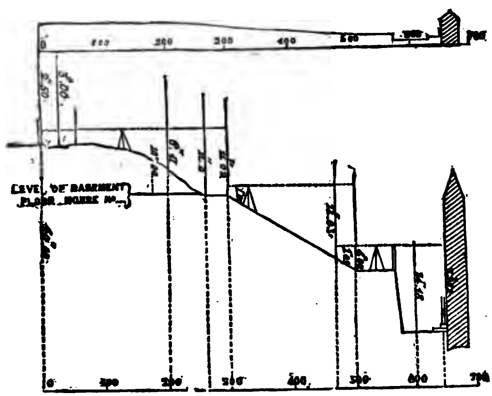
The surveyor having set up and adjusted his instrument, the staff-holder proceeds to the point at which the levels are to commence, and holds up his staff perfectly upright and turned towards the surveyor, who notes the division of the staff which coincides with the horizontal wire in the telescope, and enters the same in his level-book; the staff-holder then proceeds to the next point, and the reading of the staff is noted as before; and this is repeated until the distance or the difference of level makes it necessary for the surveyor to take up a fresh position. While this is being done, the staff-holder remains stationary, until, the level being adjusted again, he carefully turns the face of the staff so as to be visible from the instrument in its new position, and a second reading of the staff is noted, after which he proceeds forward as before for a fresh set of observations.

304. In every set of observations the first is called a Backsight, and the last a Foresight. The remaining observations are called intermediates, and are entered accordingly. It will be seen that an error in an intermediate reading is confined to the point where it occurs; but a mistake in a back or foresight is carried throughout the whole work, and therefore every care should be taken to insure accuracy in observing these sights.

305. The surveyor should commence and close his work by setting the staff on some well-defined mark, which can readily be referred to at any subsequent period, such as a door-step, plinth of a column, &c. These marks are called bench marks, written B M, and are essential for either checking the work or carrying it on at a subsequent period.

306. The reduction of the levels to a tabular form for use is a simple arithmetical operation, which will be readily understood by examination of the annexed example of a level book, and of the accompanying section*, fig. 105. The difference between the successive readings in any set of

Fig. 105.



observations is the difference of level between the points where the staff was successively held up, and by simple addition or subtraction, according as the ground rises or falls, we might obtain the total rise or fall of the ground above or below the starting point; but as this would require two columns, one for the total rise, and one for the total fall, it is simpler to assume the starting point to be some given height above an imaginary horizontal *datum line*, drawn below the lowest point of the ground, to which level all the heights are referred in the column headed total height above datum line.

307. The accuracy of the arithmetical computations is

* In plotting sections of ground, it is usual to make the vertical scale much greater than the horizontal, which enables small variations of level to be easily measured on the drawing without its being extended to an inconvenient length. This is shown in the lower half of fig. 105. The upper part of the figure shows the section plotted to the same horizontal and vertical scale.

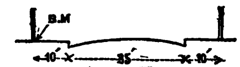
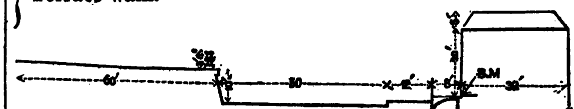
proved by adding up the foresights and backsights, and, deducting the sum of the former from that of the latter (the height of the first B M having been previously entered at the top of the page as a backsight), the remainder will be the height of the last B M, and should agree with the last figures in the column of total heights.

308. In leveling the site of a proposed building, if no suitable object presents itself for a permanent B M for future reference, a large stake, hooped with iron, should be driven into the ground in some convenient place where it will not be disturbed. The height of this stake being then carefully noted and marked upon the elevations and sections of the building, it will serve as a constant check on the depths of the excavations, and the heights of the different parts of the work, until the walls reach the level of the principal floor, when it will no longer be required.

309. We must not leave the subject of levels without mentioning a very useful instrument, called the water level, which consists of a long flexible pipe, filled with water, and terminating at each end in an open glass tube. When it is required to find the relative heights of any two points, as, for instance, the relative levels of the floors of two adjoining houses, the two ends of the tube are taken to the respective points, the tube being passed down the staircases, over the roofs, or along any other accessible route, no matter how circuitous, and the required levels are found by measuring up from the floors to the surface of the water, which will of course stand at the same level at each end of the tube.

WORKING DRAWINGS.

310. The architect, being furnished with the plan and levels of the site of his operations, and having caused a careful examination to be made of the probable nature of the foundation by digging pits or taking borings, proceeds to make out his working drawings.

Readings of the Staff.			Difference of Readings.		Reduced levels.		Remarks.
Back sight.	Inter-mediate.	Fore sight.	Rise.	Fall.	Total height above datum line.	Distance in feet.	Levels of Building Ground at —— (Date).
40·00 Height of 1st BM above datum.							
2·50	...	...	...		40·00	—	B M on doorstep of garden, No. — Park Road.
	3·00	...	...	0·50	39·50	30	On centre of Park Road. 
	10·00	...	...	7·00	32·50	...	Level of basement floor at No. — * * * Terrace.
	11·00	...	...	1·00	31·50	260	Terrace walk.
1·60		11·02	...	0·02	31·48	300	
2·05		12·03	...	10·43	21·05	475	
	4·00	...	...	1·95	19·10	500	
	14·18	...	...	10·18	8·92	600	Centre of Lower Road.
		13·32	0·86	...	9·78	...	B M top of doorstep, No. — Lower Road.
46·15							
36·37		36·37					
9·78	Reduced level of last B M.						

It is not sufficient for the execution of the working drawings that the draughtsman should be acquainted with the ordinary principles of geometric projection. He must also be thoroughly conversant with perspective, and with the principles of chiascuro, or light and shade, or he will work at random, as the geometrical projections which are required for the use of the workman give a very false idea of the effect the work will have in execution.

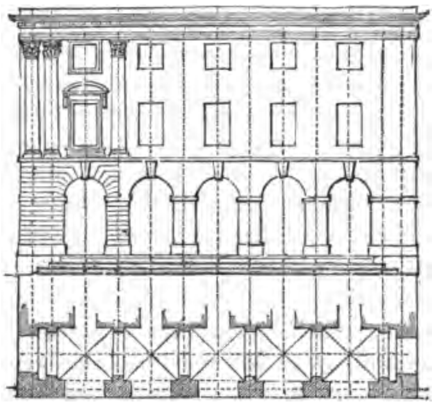
311. Working drawings may be divided under three heads, viz.:—Block plans, General drawings, and Detail drawings:

I. *Block plans.*—These show the outline only of the intended building, and its position with regard to surrounding objects. They are drawn to a small scale, embracing the whole area of the site, and on them are marked the existing boundary walls, sewers, gas and water mains, and all the new walls, drains, and water-pipes, and their proposed connection with the existing ones, so that the builder may see at a glance the extent of his operations.

A well-digested block plan, with its accompanying levels, showing the heights of the principal points, the fall of the drains, &c., is one of the first requisites in a complete set of working drawings.

II. *General Drawings.*—These show the whole extent of the building, and the arrangement and connection of the different parts more or less in detail, according to its size and extent. These drawings consist of *Plans* of the foundations, and of the different stories of the building, and of the roofs; *Elevations* of the different fronts; and *Sections* showing the heights of the stories, and such constructive details as the scale will admit of. These drawings are carefully figured, the dimensions of each part being calculated, and its position fixed by reference to some well-defined line in the plans or elevations, the position of which admits of easy

Fig. 106



verification in all stages of the work. This is best done by ruling faint lines on the drawings, through the principal divisions of the design, as shown in fig. 106, where the plan and elevation are divided into compartments, by lines passing through the centres of the columns, from which all the dimensions are dated each way. These centre lines are, in the execution of the work, kept constantly marked on the walls as they are carried up, so that they are at all times available for reference.

By this means, the centre lines having been once carefully marked on the building, any slight error or variation from the drawings is confined to the spot where it occurs, instead of being carried forward, as is sometimes the case, to appear only when correction is as desirable as it is impossible.

The use of these centre lines also saves much of the labor of the draughtsman, as they form a skeleton, of which only so much need be filled up as may be required to show the design of the work.

III. *Detailed Drawings.*—These are on a large scale, showing those details of construction which could not be

explained in the general drawings, such as the framing of floors, partitions, and roofs, for the use of the carpenter; the patterns of cast-iron girders and story posts for the iron-founder; decorative details of columns, entablatures, and cornices, for the carver; the requisite details being made out separately, as far as possible, for each trade; which arrangement saves much time that would otherwise be wasted in referring from one drawing to another, and, which is still more important, insures greater accuracy, from the workman understanding better the nature of his work.

In making the detailed drawings every particular should be enumerated that may be required for a perfect understanding of the nature and extent of the work. Thus, in preparing the drawings for the iron-founder, every separate pattern should be drawn out, and the number stated that will be required of each.

This principle should be attended to throughout the whole of the detailed drawings, as, in the absence of such data, it is very difficult to prepare correct estimates for the execution of the work, without devoting more time to the study of the drawings than can generally be obtained for that purpose.

SPECIFICATION.

312. The drawings being completed, the architect next draws up the specification of the intended works. This is divided under two principal heads—1st, the conditions of the contract; and, 2d, the description of the work.

The title briefly states the nature and extent of the works to be performed, and enumerates the drawings which are to accompany and to form part of the written specification.

313. *Conditions of Contract.*—Besides the special clauses and provisions which are required by the particular circumstances of each case, the following clauses are inserted in all specifications:

1. The works are to be executed to the full intent and meaning of the drawings and specification, and to the satisfaction of the architect.

2. The contractor to take the entire charge of the works during their progress, and to be responsible for all losses and accidents until their completion.

3. The architect is to have power to reject all improper materials or defective workmanship, and to have full control over the execution of the works, and free access at all times to the workshops of the contractor where any work is being prepared.

4. Alterations in the design are not to vitiate the contract, but all extra or omitted works are to be measured and valued according to a schedule of prices previously agreed upon.

5. The amount of the contract to be paid by instalments as the works proceed, at the rate of — per cent. on the amount of work done, and the balance within ——— from the date of the architect's final certificate.

Lastly. The works are to be completed within a stated time, under penalties which are enumerated.

314. *The description of the works* details minutely the quality of the materials, and describes the manner in which every portion of the work is to be executed, the fulness of the description depending on the amount of detailed information conveyed by the working drawings, care being taken that the drawings and specification should, together, contain every particular that is necessary to be known in order to make a fair estimate of the value of the work.

315. The chief merit of a specification consists in the use of clear and explicit language, and in the systematic arrangement of its contents, so that the description of each portion of the work shall be found in its proper place; to facilitate

reference, every clause should be numbered and have a marginal reference attached, and a copious index should accompany the whole.

BILLS OF QUANTITIES.

316. The surveyor, being furnished by the architect with the drawings and specification, proceeds to take out the quantities for the use of the parties who propose to tender for the execution of the work. This is done in the same way that work is measured when executed, except that the measurements are made on the drawings with a scale instead of on the real building with measuring rods.

317. In taking out quantities there are three distinct operations: 1st, taking the dimensions of the several parts of the work, and entering them in the dimension book; 2dly, working out the quantities, and posting them into the columns of the abstracts, which is called *abstracting*; 3dly, casting up the columns of the abstracts, and bringing the quantities into bill.

318. The dimension book is ruled, and the dimensions entered as in the following examples:

No.	Dimension.	Quantity.	Description.
	ft. in.	ft. in.	
16	14 0		
	0 10	38 10	Memel fir framed joists to front room ground floor.
	0 2½		

In this example the work measured consists of sixteen joists; each 14 ft. long and 10 in. deep and 2½ in. thick; and the total quantity of timber they contain amounts to 38 ft. 10 in. cube.

Dimension.	No. of bricks in thickness.	Quantity.	Description.
ft. in. 20 6 11 6	2½	ft. in. 235 9	Stock brickwork in mortar to front wall, from footings to 1st set-off.

319. In preparing the abstract for each trade, the surveyor looks over his dimensions to see what articles he will have, and rules his paper into columns accordingly, writing the proper heads over each.

The principal point to be attended to in abstracting quantities is to preserve a regular rotation in arranging the different descriptions of work, so that every article may at once be found on referring to its proper place in the abstract.

No fixed rules can be given on this head, as the form of abstract is different for every trade, and must be varied according to circumstances ; but, as a general principle, articles of least value should be placed first. Solid measure should take precedence of superficial, and superficial of lineal, and miscellaneous articles should come last of all ; or, in technical terms, the rotation should be, 1st, cubes ; 2nd, supers.; 3rd, runs ; and, lastly, miscellaneous.

320. In bringing the quantities into bill, the same rotation is to be observed as in abstracting them, care being taken that every article is inserted in its proper place, so that it may readily be found in the bill.

The limits of this volume prevent our going into much detail on the subject of builders' accounts, and we must therefore confine ourselves to laying before the reader a skeleton estimate, which will give him a tolerable idea of the manner in which the several kinds of artificers' work are abstracted and brought into bill.

321. Estimate for the Erection of ——— at ———, for ———, according to Specification and Drawings numbered 1 to —, prepared by ———, Architect. (Date.)

Foundations.

yds. ft.			Dolls.	Cts.
— — cube	Excavation to foundations, (including cofferdams, pumping, &c.) . . .	at —		
— — "	Concrete			
ft. in.				
— — "	Timber in piles driven — ft. through, (describe the material,) including ringing, shoeing and driving, but not ironwork . . .			
— — "	Do. in 6-in. planking, spiked to pile-heads . . .			
cwt. qrs. lbs. — — —	Wrought iron in shoes to piles			
	Total of foundations to be carried to summary .			

Bricklayer.

rods. ft.				
— — supl	Reduced brickwork in mortar	at —		
— — "	Reduced brickwork in cement			
sqrs. ft.				
— — "	Tiling (describing the kind, whether plain or pantiling, if single or double laths, &c., &c.)			
yds. ft.				
— — "	Bricknogging to partitions .			
— — "	Paving, (of various descriptions)			
	And all other articles valued per yard superficial.			
ft. in.				
— — "	Gauge arches			
— — "	Facings (with superior description of bricks, specifying the quality) . . .			
— — "	Cutting to arches or splays .			
	And all other work valued by the foot superficial.			
— — run	Barrel or other drains (specifying size, &c.) . . .			

Carried forward $

BRICKLAYER, *continued.*

					Dolls.	Cts.
			Brought forward . .			
—	—	run.	Tile creasing . . .	at —		
			And all other articles valued by running measure.			
		Nos.	Chimney pots, each ; bedding and pointing sash and door frames, each ; and all miscellaneous articles . .			
			Total of bricklayers' work to be carried to summary			

MASON.

yds.	ft.					
—	—	cube	Rubble walling . . .	at —		
—	—	"	Hammer-dressed walling in random courses . .			
ft.	in.					
—	—	"	Stone (describing the kinds).			
—	—	supl.	Labor on above (as plain work, sunk, moulded or circular work) . . .			
—	—	"	Hearths, pavings, landings, &c., beginning with the thinnest			
—	—	"	Marble slabs, beginning with the thinnest and inferior qualities			
—	—	run	Window sills, curbs, steps, copings, &c. . . .			
—	—	"	Joggle joints, chases, &c. .			
		Nos.	Mortices and rail holes, &c.—dowels, cramps, and other articles numbered . .			
			Total of masons' work to be carried to summary .			

CARPENTER AND JOINER.

sqrs.	ft.					
—	—	supl.	Labor and nails to roofs, floors, or quarter partitions	at —		
—	—	"	Battenings and boardings according to description .			

Carried forward . . . $

CARPENTER & JOINER, *continued.*

			Description		Dolls.	Cts
—	—	supl.	Floors, according to description, beginning with the inferior and ending with the best descriptions .	at —		
			And so on for all work valued by the square.			
ft.	in.					
—	—	cube	Memel fir, according to description, as fir bond, fir framed, wrought and framed, wrought, framed, and rebated, &c. . . .			
—	—	"	Do. proper door and window cases			
			Then oak, and superior descriptions of timber, in the same way.			
			Then the superficial work, as—			
—	—	supl.	½-in. deal rough linings, and so on with the different thicknesses of deals according to the labor on them; arranging them according to their thickness, and the amount of labor on them, beginning with the thinnest			
			Then oak plank or mahogany in the same way.			
			Then take the framed work, as—			
—	—	"	1¼-in. deal square-framed inclosure to closets, and so on with the rest of the framed work, as doors, shutters, sashes, frames, &c., according to description . .			
			Then the work valued by running measure, as—			
—	—	run	2¼-in. Spanish mahogany moulded, grooved, and beaded handrail . . .			
			Then the numbers, as—			
		Nos.	Mitred and turned caps, fixing iron balusters, &c.			

Carried forward . . $

CARPENTER & JOINER, *continued.*

					Dolls.	Cts.
			Brought forward . .			
			Lastly — The Ironmongery, every article of which should be carefully described.			
			Total of carpenter and joiners' work to be carried to summary . .			

SLATER.

sqrs.	ft.					
—	—	supl.	Countess, or any other kind of slating, according to description	at —		
ft.	in.		Then slate slab, as—			
—	—	"	Inch shelves, rubbed one side, beginning with the slabs of least thickness, and arranging them according to the labor bestowed on them .			
			Then the work valued by running measure, as—			
—	—	run.	Patent saddle-cut slate ridge			
			Lastly—the numbers, as—			
		Nos.	Holes, cut, &c. . . .			
			Total of slaters' work to be carried to summary .			

PLASTERER.

			First the superficial quantity of plastering, as—			
yds.	ft.					
—	—	supl.	Render float and set to walls, beginning with the commonest, and proceeding through the different descriptions of two and three coat work, up to the stuccoes and superior work .	at —		
			Then the whitewashing, distempering, &c. . . .			
			Next the run of cornices, architraves, reveals, &c., as—			

Carried forward . $

PLASTERER, *continued.*

		Dolls.	Cts.
ft. in.	Brought forward .		
— — run.	Plain cornice to drawing-room, 14 in. girt .		
	And lastly the numbers, as—		
Nos	4 mitres, 1 centre flower, 30 in. diameter, &c., &c.		
	Total of plasterers' work to be carried to summary .		
	SMITH AND IRON-FOUNDER.		
	Begin with the cast-iron, as—		
tns. ct. qrs. lb. — — — —	Cast-iron in No. 4 girders, including patterns, painting, and fixing . . . at —		
	N. B.—State the No. of patterns.		
	Then the smaller castings, as—		
	Railings, balconies, columns, &c.		
	Then the wrought iron, as—		
— — — —	Wrought iron in chimney bars, straps, screw bolts, railings, &c. . . .		
	Then the articles sold by running measure, as—		
yds. ft. — — run.	Cast-iron gutters, water-pipes, &c. . . .		
	Lastly, the numbers, as—		
Nos	Stoves, coal-plates, stable-fittings, &c.		
	Total smith and iron-founders' work to be carried to summary . .		
	BELL-HANGER.		
	Number the bells, and describe the mode of hanging, as—		

Carried forward . . $

Bell-hanger, *continued.*

			Dolls.	Cts.
	Brought forward . .			
Nos. —	bells hung with copper wires in concealed tin tubes, with bells, cranks, and wires complete . .			
	And then enumerate the ornamental furniture to the different pulls . . .			
	Total of bell-hangers' work to be carried to summary			
	Plumber.			
cwt. qrs. lbs. — — —	Cast lead laid in gutters, hips, ridges, flats, cisterns, &c.; including all solder, wall hooks, nails, &c. .	at —		
— — —	Milled do. do. . .			
	Then socket, rain-water, funnel pipes, and other work valued by the lineal foot, as—			
ft. in. — — run.	Inch drawn pipes . .			
	Lastly the numbers, as—			
Nos.	Joints, plugs, and washers, air traps, brass grates, cocks, copper balls, pumps, water closets, apparatus, &c.			
	Total of plumbers' work to be carried to summary .			
	Painter.			
yds. ft. — — supl.	Of painting, according to description, specifying the number of oils, and whether common or extra colors, beginning with the work in fewest coats, and finishing with the most expensive descriptions . .			
	Carried forward .	$		

PAINTER, *continued.*

ft.	in.				Dolls.	Cts.
			Brought forward .			
			Then the running work, as—			
—	—	run.	Skirtings, plinths, window sills, &c.			
			Lastly the numbers, as—			
		Nos.	Frames, squares, chimney pieces, &c. . . .			
			Total of painters' work to be carried to summary .			

GLAZIER.

ft.	in.				Dolls.	Cts.
—	—	supl.	Glazing, according to description, specifying size of squares, and quality of glass	at —		
			Then, the stained and other ornamental glass; and, lastly, the plate glass.			
			Total of glazier's work to be carried to summary .			

PAPER-HANGER & DECORATOR.

					Dolls.	Cts.
yds.	ft.					
—	—	supl	Distempering, according to description . . .	at —		
ft.	in.					
—	—	„	Scagliola slabs do. . .			
yds.	ft.					
—	—	run	Gold mouldings . . .			
		Nos.	Pieces of paper hung, according to description, including preparing walls— Hanging, lining, paper, and pumicing do. . .			
		„	Dozen of borders . . .			
			Total of paper-hanger and decorator's works to be carried to summary .			

SUNDRIES.	DOLLS.	CTS.
Temporary fencings—watching and lighting works		
Office for clerk of works		
District surveyor's fee		
Fire insurance		
Surveyor's charge for bills of quantities		
Total sundries to be carried to summary		

SUMMARY OF BILLS.		
Foundations		
Bricklayer		
Mason		
Carpenter and joiner		
Slater		
Plasterer		
Smith and iron-founder		
Bell-hanger		
Plumber, painter, and glazier		
Paper-hanger and decorator		
Sundries		
Total amount of estimate		

322. The surveyor furnishes the builder, whose tender is accepted, with copies of the drawings from which the quantities have been taken off.

By reference to these, the builder can at all times satisfy himself that the detailed drawings, furnished for the execution of the work, contain nothing beyond what he has contracted for.

Copies of the drawings and specification are attached to the contract deed, and are signed by the builder and other parties respectively concerned.

323. It scarcely ever happens that a large undertaking can be carried into execution without considerable departure from the contract designs, especially in the matter of foundations and underground work ; the exact nature and extent of which must often be uncertain until the works are commenced.

To provide for these contingencies without setting aside the contract, the builder's estimate is accompanied by a schedule of prices at which he undertakes to execute any additional work that may be required, or to value any work that may be omitted. This schedule should be carefully drawn out, so that there shall be no dispute as to its meaning; thus, under the head of brickwork, it should be clearly understood whether centering is included in the price named, or whether it is to form an additional charge; with iron-founders' work, whether the price includes patterns; and so on with every description of work.

324. Architects are remunerated by a commission of 5 per cent. on the amount expended under their direction, besides traveling expenses, salary of the clerk of the works, and occasionally other charges, according to circumstances.

THE END.